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ORGANISATIONAL EVOLUTION AND CHANGE: A COMPLEX SYSTEMS APPROACH

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Modelling Organisational Evolution and Change - a Complex Systems Modelling Perspective

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Dedication

I would like to dedicate this work in love and gratitude to the memory of the late Daniel Hunter Strathern and Kathleen Mary Strathern (nee Doherty)

"*We both step and do not step in the same rivers. We are and are not.*"
Heraclitus, fragment DK B49, circa 504-501 BC

"Tell me, who was it who first declared, proclaiming it to the whole world, that a man does evil only because he does not know his real interests, and if he is enlightened and has his eyes opened to his own best and normal interests, man will cease to do evil and at once become virtuous and noble, because when he is enlightened and understands what will really benefit him he will see his own best interest in virtue, and since it is well known that no man can knowingly act against his best interests, consequently he will inevitably, so to speak, begin to do good. Oh, what a baby! Oh, what a pure innocent child!"
Fyodor Dostoevsky, Notes from underground, 1864

"Let me recite what history teaches. History teaches."
Gertrude Stein, If I Told Him: A Completed Portrait of Picasso,1923

Abstract

The cumulative output of these papers emphasise that modelling organisational evolution and change from a complex systems perspective makes a significant contribution to organisational studies and brings new insight and understandings both to theory and practice. It is also true that the studies and modelling presented in these papers has pushed forward the boundaries of complex systems science, again both in theory and practice.

The papers have made new findings and understandings of the processes, drivers and outcomes of the evolution of social systems and organisations through the development of new evolutionary models and frameworks that contribute both to organisational and complexity sciences. They have through a number of innovations based in complexity science addressed questions in organisational science concerning the importance of knowledge and learning, together with questions about the evolution and survival of organisations and industries. These innovations have played back into and developed complexity science.

Prologue

This work is presented under Cranfield University Regulation 39, and 39.6 and 39.7 in particular, as last amended: 12 May 2005

39.6 Notwithstanding the provisions of para 39.5, a staff candidate may be permitted by the Faculty Board, on the recommendation of his Head of School, to present published work for examination, instead of a thesis, provided that:
(a) the publications represent a substantial, continuous and coherent body of work on a particular theme; and
(b) the candidate has been a member of the staff for not less than three years and his published work is directly relevant to his responsibilities as a member of the staff; and
(c) in the opinion of the Head of School, it would be wasteful of effort and hence detrimental to the candidate's other responsibilities to require him to convert his published work into a thesis; and
(d) a period of at least one year shall have elapsed since initial registration as a staff candidate.

39.7 The publications submitted in lieu of a thesis shall be presented in triplicate and accompanied by:
(a) a list of the publications presented; and
(b) an exposition of the work contained in the publications presented; and
(c) a declaration specifying whether or not any part of the work has been presented for any other academic distinction or professional qualification, and the extent of the candidate's contribution to any part of the work which may have been published or performed jointly with others.

Acknowledgements

The numbers of those who have helped over the many years to the completion of this thesis are too many and their contributions too great to be fully acknowledged. I am therefore restricting myself to a few of the main peaks in the mountain range of my debt, and offer my sincere apologies and thanks to all of those whom I have missed. First of course I wish to thank my co-authors whose deep knowledge, friendship and help has contributed so much: Karin Breu, Christopher Hemingway, David Bridger, Peter Allen, Jeff Johnson, James Baldwin and Jean Boulton. Little if any of this would have been possible without them. I would also like to thank those who awakened me to my intellectual journey and stood behind and beside me on the way: Paul Strathern, Howard Martin, Michael Lesser and particularly my mentor, friend, colleague and co-author Peter Allen. The deep and broad pool of their knowledge has supported me throughout my halting endeavours. Finally I must express my gratitude to my family, Ali, Ben and my beloved wife Liz, for all their forbearance and support over the years.

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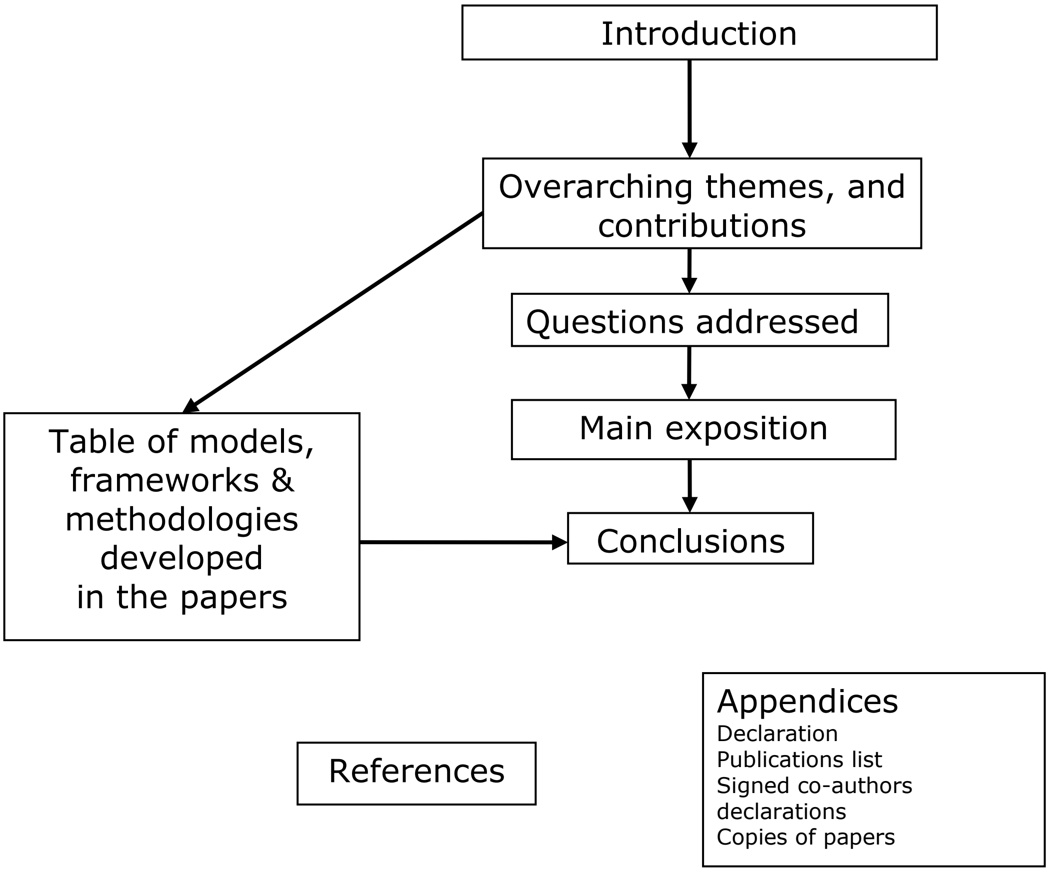


Figure 1 Structure of synoptic paper

1.0 Introduction

(references in this work of the form 2005b:16 refer to the submitted works, in this case 2005b page 16)

Companies and markets form integrated, but open, co-evolutionary systems. The works submitted here take a Complexity Science perspective and use it to develop complex systems models and modelling to understand and explore this and in order to do so develop new types of complex systems models and complex systems modelling theory. The results give new insights and understandings at various levels of social systems. This ranges from individual actors through organisational structures to whole markets, industries and organisational eco-systems. This builds a picture of how organisations and organisational eco-systems evolve and what the implications of that are for the individuals, companies and organisations within them.

Prior to the submitted papers complex systems science Allen (1999) had shown the importance of adaptability to complex systems theory. Whilst within organisational science there was also recognition of the importance of flexibility and adaptability to an organisation's viability and sustainability (Golden and Powell, 2000). It is one of the contentions of the present works that this is because organisations are complex systems that are adapting to, and co-evolving with, their environment.

The structures investigated in these papers range in level from markets through supply chains and industries to individual companies and even down to those working within them. The insights gained and the lessons to be drawn from this work correspondingly have implications at all levels. Evolution whether of organisations, such as markets or companies, does not operate in isolation. Complexity science has shown that evolution is open (Prigogine 1980, Allen 1976) and rests on the three dynamic pillars of environment, internal organisation and micro-diversity (Gillies, 2000). Organisations with strategies, organisational structures, processes and supply chains act within industries, economic markets with consumer choice, and demand side supply chains. This is the environment within which, and with which they evolve. The papers submitted investigate this through the development of complex systems modelling and models with results that explain and confirm some old insights and lessons whilst also bringing new findings and insights to bear on the processes involved.

1.1 Complexity and complex systems modelling

1.11 From Poincaré to Bernard

Since the time of Newton no analytical solution has been known for systems that involve the dynamics of more than two bodies acting freely on each other. This is classically called the 'Three Body Problem', now more commonly generalised as the '*n*-body problem' and which still greatly exercises the minds of mathematicians and physicists (Kim, E. et al., 2008)

In celestial mechanics Henri Poincaré, the great French mathematician often described as the last of the universalists because of his immense contributions throughout many branches of pure and applied mathematics and the physical sciences, studied the classical Three Body Problem (Bell, 1937). A prize had been offered by King Oscar II of Sweden in the 1880's for finding a solution to the question: Given the present masses, velocities, motions and locations of *n* bodies is it possible to determine their future locations, etc. throughout time? Poincaré did not solve the problem but was awarded the prize in 1889 for his work on the problem. The jury consisted of the mathematicians Weierstrass, Hermite, and Mittag-Leffler. Weierstrass wrote to Mittag-Leffler 'you may tell His Majesty that this work cannot indeed be considered as furnishing the complete solution of the question proposed, but that it is nevertheless of such importance that its publication will inaugurate a new era in the history of Celestial Mechanics'. Indeed this was so and after publication (of a corrected version since the first had faults) it has revolutionised dynamics (Boyer and Merzbach, 1989) and laid one of the important foundations of complexity science (Nicolis, 1995).

What Poincaré discovered was that the phase portrait of the stable and unstable orbits of the planets, he particularly studied the solar system, formed what he described as a heteroclinic tangle. This tangle consisted of stable and unstable orbits that were 'braided' together like a rope so tightly that there were infinitesimal distances between stable and unstable orbits (Abraham and Shaw, 1985). The significance of this finding for the dynamics of more general systems did not begin to be fully appreciated until the middle of the 20th century.

Another key discovery, though again it took a number of years to appreciate its significance, was the discovery by Benard in 1900 of the convection cell, now known as the Rayliegh-Bernad cell (Nicolis, 1995). What Bernard did was to trap a relatively thin layer of fluid (liquid or gas) between two heat conducting plates held at different temperatures so that there is a flow from the lower, hotter plate through the fluid to the colder plate. When the temperature difference is small there is no organisation in the fluid and the molecules move in a totally random manner transporting the heat from the hotter plate to the colder. At a certain point as the temperature difference increases there onsets an extraordinary phenomena. The fluid develops into a regular pattern of hexagonal cells with fluid upwelling in the centre of the cells and sinking at the edges (see Fig. 1). This spatial patterning is stable over time and quite a large range of temperature differences but when the temperature difference is sufficiently high it breaks up and a constantly shifting tangle of turbulent flows emerges. Again there is no discernible spatial pattern to the movement of the fluid.

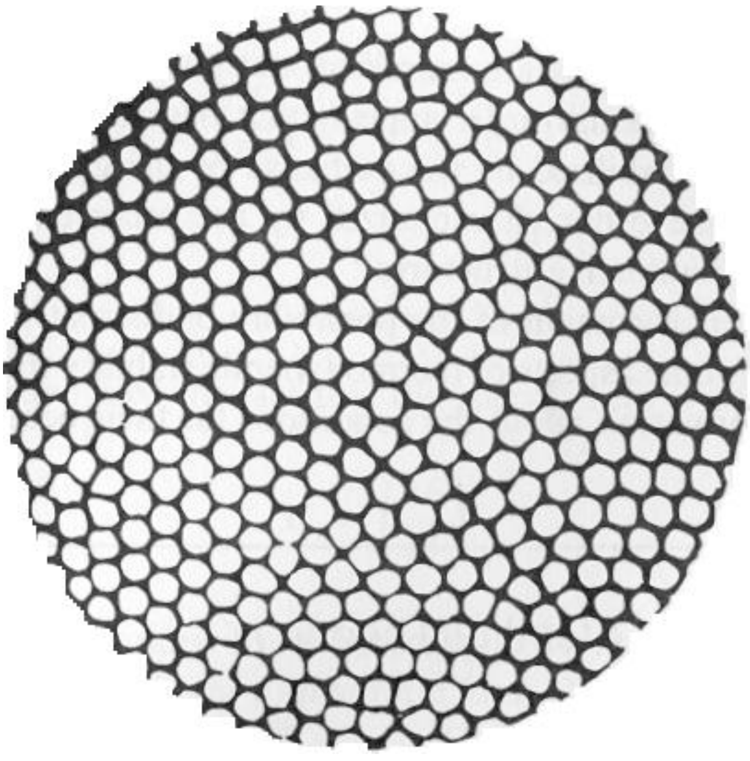


Figure 2 Spatial pattern of convection cells, viewed from above, in a liquid heated from below.
(from Prigogine, 1980)

What was surprising about both these discoveries was that purely mechanical systems could have such rich and exotic behaviours that they no longer appeared to be 'mechanical'. They *seemed* to be imbued with a will of their own and infused with some teleological principal. On the one hand the seemingly absolute mechanical order of the classical celestial bodies that was apparently decreed by Newtonian mechanics actually contained a chaotic tangle of instability and stability that could lead to structures forming and reforming in what often appeared to be an endless cycle, or the whole system suddenly and unexpectedly flying apart. On the other hand from the randomness and chaos of the movement of the unimaginably large number ($>10^{23}$) of individual molecules all acting individually and apparently doomed to perpetual chaos by the Second Law of thermodynamics comes pattern and stability as if by some 'hidden hand'. In these two discoveries we also have the prototypical forms of two major strands of thought in complexity science, 'chaos out of order' and 'order out of chaos'.
However do these two apparently opposed systems have anything in common? Surprisingly the answer is yes. Both exhibit a number of the typical properties of complex systems (Allen, 1999). These are: non-linearity, sensitivity to initial conditions, symmetry breaking, emergence and self-organisation. Non-linearity is at the heart of such systems, feedback loops within the actions of the bodies or molecules making up the system tend to amplify some behaviours and dampen others leading to the braiding of stable and unstable solutions in Poincaré's case and to patterning in the Bernard cell. They also both exhibit sensitivity to initial conditions. In the *n*-body problem extremely small changes in initial conditions leads rapidly to very different configurations, some stable some not. Whilst in the Bernard cell it is not possible to predict, however carefully the experiment is carried out, the precise location and dimensions of the cells. This is dependent on the exact location and velocity of the molecules at the beginning of the experiment and a number of other factors that would have to be known below the level that quantum probability factors come into play. Below this level location and velocity cease to have a separate meaning. (Feynman, 1985).

Both systems also break symmetry. Here the argument is a little more arcane but very important as it is only through the breaking of symmetry that new structural attractors

(2005c) and dimensions emerge. The *n*-body problem breaks symmetry when there are more than two bodies. If there are two bodies the solution is analytic and stability and instability is easily determined and normally changes little for small changes in initial configuration. At three bodies there is a break where this is no longer true and the beating of a butterfly's wing may move the solar system from an ultimately stable configuration to an unstable one and back again. Certainty has disappeared but structure can emerge. In the convection cell the symmetry that is broken is spatial. At low temperature differences, before the onset of cell formation, one small region cannot be differentiated from any other one. Whilst after cell formation there are regions of up-welling and down-welling fluid with distinct boundaries between the cells. The cells themselves form a regular and stable spatially discrete grid (fig 1).

Finally both systems exhibit emergence and self-organisation. The *n*-body problem can exhibit quite extraordinary behaviours, one of the clearest examples exhibiting both emergence and self-organisation are the rings of Saturn (fig. 2). Here from what was originally a cloud of rocks, small particles and a planetary body acting only under the influence of gravity, emerged, through self-organisation, the delicate and beautiful structure that we observe today. These wonderful structures are sculpted and given defined edges and gaps by a number of shepherd satellites which are moonlets that orbit just outside, or within the rings, which perform a complex, intricate and incalculable dance that at least for the moment maintains the ring structure.

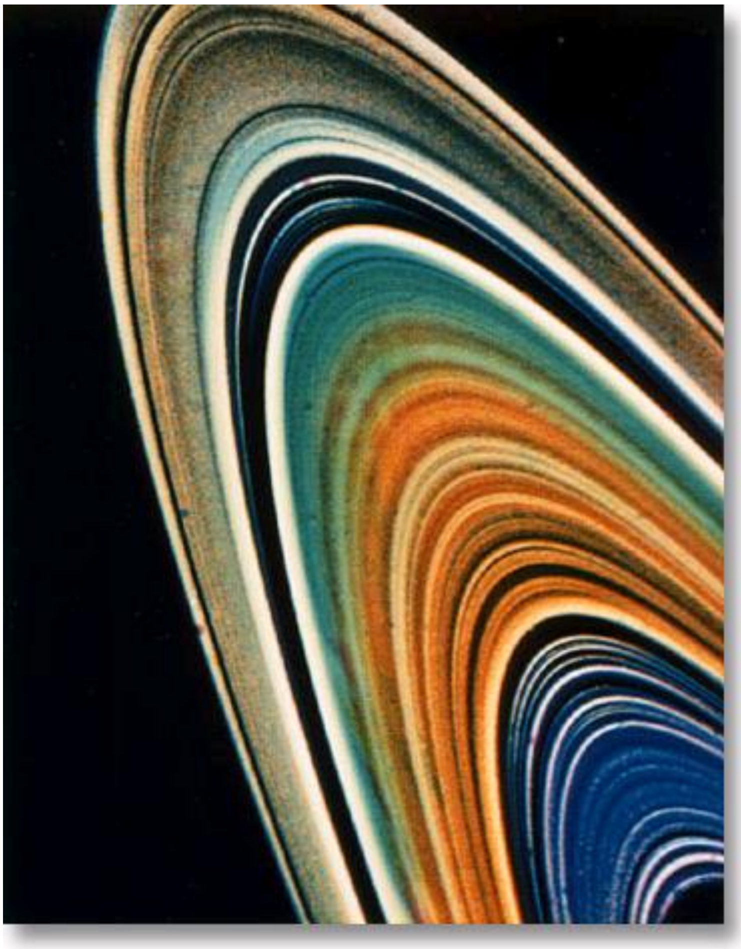


Figure 3 The rings of Saturn with two of the shepherd satellites' shadows visible on and just in from the outer ring on the left (colour enhanced).
(from http://saturn.jpl.nasa.gov/news/features/saturn-story/index.cfm)

In the case of the Rayleigh-Bernard convection the molecules of the fluid self-organise to form the emergent pattern of the cells. Where before cell emergence there was no intrinsic dimensions of distance or direction, after cell emergence there is. The cells are aligned in a hexagonal grid allowing one to talk of points that are, say, four cells away from each other along a grid line.

Weaver's classification

In a seminal paper in 1947 Warren Weaver (Weaver, 1947), better known for laying the foundations of information theory with Claude Shannon (Shannon and Weaver, 1949), laid out a classification for scientific problems. He classified them as:

- Problems of Simplicity, these are the problems dealt with by classical 'Newtonian' science.
- Problems of Disorganised Complexity, these are the problems of statistical mechanics and by extension those problems involving large numbers of objects that are amenable to statistical analysis and probability theory.
- Problems of Organised Complexity, this is the first definition of complexity science. He talked of 'a sizable number of factors which are interrelated into an organic whole.'

Though his definition of Organised Complexity has needed to be extended his classification has many merits and forms a backcloth to the discussions on modelling assumptions and the complexity framework (2005b). This framework extends and expands his understanding.

1.12 Modelling complex systems

Although complexity science traces its origins to Poincare's (1890) mathematical work on the three body problem in physics and astrophysics, which led to an understanding of the unpredictability of non-linear dynamical systems. It was also framed by Bernard's (1901) unrelated work which through empirical studies and experiments in fluid dynamics came to the same results. Following on from these seminal findings the foundational work of Prigogine (1955,1962, 1980, 1984, 1997) on the chemistry and thermodynamics of open systems far from equilibrium led to a wide body of work that McKelvey (1999) characterises as the European (as opposed to the North American) school of complexity. This includes amongst others the works of: Eigen and Schuster (1979) on self-organisation in natural systems, Allen (1975, 1976) on evolutionary adaptation in biological systems, Haken (1983) on fast and slow control parameters in systems, very much in the Hegelian Master/Slave school of thought, and Horsthemke and Lefever (1984) on noise induced transitions. All these have led on more recently to a modelling approach to human and natural systems that is based in complex dynamical systems theory, Allen and Sanglier(1981), Allen and McGlade (1987) Weidlich and Haag (1983), Weidlich (1991, 2002); Cramer's Sociodynamics (1993), Helbing (1995, 2005). A further thread in this school was Atkin's (1972, 1981) investigations on connectivity giving rise through algebraic topology to q-analysis which was further developed and applied by Johnson (1990, 1991, 2005) and which leads on directly to Freedom Analysis in one of the presented papers (Strathern 2005)

The North American school also traces its antecedents through Poincare and Benard but then looks more towards Madelbrot's (1961, 1963, 1975) work on fractal geometry and its applications to economics, Lorenz's (1963, 1972) work on fluid dynamics and atmospherics, Thom's (1975) catastrophe theory and most significantly on to the body of work associated with those at the Santa Fe Institute: Kauffman (1969, 1993, 2000) on fitness landscapes, Wolfram (1983, 1986) and Langton (1989) on cellular automata, Arthur (1983, 1988) on positive feedback effects in economics, Casti (1997, 1994, 1992a&b) on simulation and on surprises. In the North American school too there have also been investigations of networks and connectivity but from a different perspective. This started with Millgram's (1967) initial small world experiment for which Solomonoff and Rapoport (1951) had already laid out the mathematical foundations using graph theory. This, picked up by Pool and Kochen (1978), was then one of the foundations in social network theory. The small world thesis was further expanded at Cornell by Watts and Strogatz (1998), Watts (1999) who applied it in a wide range of applications, both within the physical and social sciences.

These two modelling schools have much in common. Early on their differences could be summarised, and slightly oversimplified, by saying that the European school looked at order out of chaos, whilst the North American school looked at chaos out of order. This corresponds to McKelvey's (2001) 1^{st} and 2^{nd} critical values of a complex system as originally put forward by Cramer (1993). More recently though the main difference has been in the modelling approaches used; the European schools use of non-linear dynamical systems theory (Nicolis 1995) and stochastic dynamical systems theory (Horsthemke and Lefever 1984) contrasting with North American adoption of agent based models (ABM) (Cohen et al. 1972, March 1991, Carley 1991).

Maguire et al. (2006) characterise complexity science in organisational studies as having two distinct and unreconciled perspectives, an objectivist and an interpretivist perspective. This roughly equates with the positivist and post-modern positions of

McKelvey (1997). Attempts have been made to bridge this gap, McKelvey (1997, 1999, 2002) from objectivism to interpretivism and Cilliers (1998, 2000a, 2000b, 2002) tries to do so from the other direction starting from what Maguire et al. (2006) calls affirmative postmodernism. Broadly speaking the papers presented here take an objectivist standpoint. However one sub-theme of the works submitted is to explain how this distinction arises and to look at ways that it can in part be bridged.

Both of the broad modelling streams, European and American, model the changes of a given system through time. However they do not look at how the systems evolve into new systems. Techniques for looking at the evolution of systems by using ideas from bifurcation theory (Kuznetsov 1998) and through genetic algorithm (GA) modelling (Holland 1975) have been developed; however they are limited in application. A third method was the introduction from biological science by McCarthy et al (1997) of organisational cladistics. But whilst an important step forward in the understanding of organisational evolution this work still gave only a static view with a single, historical, pathway. It did not look at the essentially probabilistic and dynamic evolution of organisations. In the papers submitted this is addressed in a manner that gives a richer picture of the possibilities and dynamics of organisational evolution (2005b&c, 2006a&b). And this is further enriched through the modelling the adaptability (2005a), agility (2001) and evolution (2003, 2005b, 2006a&b) of organisations from a variety of Complex Systems viewpoints.

Casti (1992b:229) pointed out that dynamical systems and dynamical systems models are based on the idea of ‘forces’ and use differential equations to model the dynamics of the system acting under these forces. As an antithesis ABMs on the other hand use ‘agents’ who are driven by rules that generate the dynamics of the system under investigation (Carley 1990). Maguire et al. (2006) points out that there is therefore a significant difference between these two methodologies. This has often led to them being used for different systems. One of the themes of the works presented is the development of a kind of ‘Hegelian’ synthesis as an overview between these methodologies through a number of modelling techniques and arguments that go some way towards resolving the differences and complementing without loosing their individual expressiveness. This is done using methods that bridge between the two and through the development of techniques and approaches that can incorporate both views. However there are also techniques developed to bridge and incorporate both empirical and theoretical approaches and sometimes to couple this with both the numerical and qualitative standpoints. The papers go on from this position to build and to develop new insights, viewpoints and modelling techniques, without having to shoehorn a qualitative modelling approach into the quasi numerical methods.

A further major problem in complex systems theory stems from the fact that complex systems are open. Prigogine's (1955, 1962) work early demonstrated that open systems behave qualitatively differently to closed ones and that they are intrinsically unpredictable. Whilst as the works submitted here show, *all* models are in the end closed, even purely descriptive ones. Complexity science can describe the openness of the world whilst complex systems modelling can model various aspects of the evolution but can never completely predict the future evolution of an organisation except perhaps in a few cases where it predicts the organisation's imminent demise.

In philosophical terms the problem of openness is exacerbated by the 'freewill problem' (Kane, 1998, Schoppenhauer 1985 edition). The natural sciences, particularly physics (Nagel 1961) and biology (Dawkins 1976), have had a reductionist approach that leads naturally to a deterministic model of nature. In the social sciences Wegner (2002) has empirically demonstrated some the difficulties implied in assuming freewill. Whilst aware of these problems Poincare's work in astrophysics and Prigogine's in chemistry has shown that even in hard physical systems emergence can drive systems into unimaginable complexity that seem to have a will of their own.

1.13 Organisational background and framing

From one viewpoint organisational evolution in market economies is framed by market capitalism. Schumpeter (1939) said: '*The essential point to grasp is that in dealing with capitalism we are dealing with an evolutionary process. ... Yet that fragmentary analysis which yields the bulk of our propositions about the functioning of modern capitalism persistently neglects it.'* and went on to talk of waves of 'creative destruction'. In economics this has led on to a wide range of insights including Nelson and Winter's (1982, 1995) Evolutionary Economics, where the original Newtonian physics based views of Walras (1874) of economics were displaced by more organic and Darwinian views. Whilst this effort continues in economics, for instance with Metcalfe's (1998, 1999) work on 'restless capitalism', organisational studies took some time to pick up on Schumpeter's theme and much later (Dosi 1984, Tushmana and Anderson 1986). More recently Mezias and Boyle (2002) looked further into the organizational dynamics of creative destruction with reference to entrepreneurship, learning and industrial ecology .

However, as Ormerod (2005) points out, despite this work there has not been much empirical study on the average lifetimes of companies. In 1987 *Forbes* magazine published a comparison between its original 'Forbes Top 100 US Companies' of 1917 and its 1987 list. Only 18 of the original companies remained in the list. The majority, 61, had ceased to exist. Senge (1990 p.16) quotes evidence that for large companies the average lifespan is about 40 years and this figure is confirmed by Collins (2001). In a more extensive study Foster and Kaplan (2001) considered the 1008 companies in the Kinsey Corporate Performance database between 1962 and 1998. They took as a prior baseline the turnover rate in the S&P 90 list of US companies during the 1920s and 1930s. In the latter they found it had been 1.5% annually and that therefore a company could expect to be on the list for 65 years on average. They argued that this regime had now changed by showing, through their study of the Kinsey database companies, that by 1998 the turnover rate in the roughly analogous S&P 500 was 10% and a company could expect to be on that list for only 10 years on average.

Senge (1990) and Foster and Kaplan (2001) argued that the best way to deal with this and maximise the life of companies was through the adoption of radical learning and transformation. However the economist Paul Ormerod and colleagues (Cook and Ormerod 2003, Ormerod 2005) have modelled the failure of US companies and found that a learning model did not give results that fit the pattern of failures. They constructed an agent based model built on basic economic principles of the evolution of companies and their final death. This model closely agreed with the empirical evidence that they and Carrol (2000) had found described the lives of companies. They used this model to explore the effects of different amounts of strategic knowledge on their evolution. And found that (Cook and Ormerod 2003, p17):

'There are two important stylised facts relating to firm survival and extinction:

· the size/frequency of extinction relationship follows a power law with exponent around –2

· the probability of extinction is highest in the early time period of a firm's life.

This falls as the firm becomes older, and eventually becomes generally invariant to the age of a firm.'

And went on to describe how their model showed:

There are very considerable returns to acquiring knowledge, for even a small amount leads to a sharp increase in the mean agent age at extinction for agents with knowledge compared to those without. Indeed, we find that as both the amount of knowledge available to firms increases and as the number of firms capable of acquiring such knowledge rises, the lifespan of agents begins to approach the limiting, full information paradigm of neo-classical theory in which agents live for ever.

However, even with relatively low levels of knowledge and numbers of agents capable of acquiring it, the model ceases to have properties which are compatible with the two key stylised facts on firm extinctions. The clear implication is that firms have very limited capacities to acquire knowledge about the likely impact of their strategies.

In the model they found that the best fit was a random, power law, model of failure. This was also akin to the failure rates predicted by complexity science in some natural random phenomena by Bak's theory self-organised criticality (Bak and Paczuski 1995, Bak 1996) and again echoed the blowing of Schumpeter's (1942) 'gales of creative destruction'.

There is a problem here between understanding the evolution and failure of companies in general, given by Ormerod's model and the view of the particular company in Senge's idea of the 'learning organisation' or Foster and Kaplan's idea of the company successfully managing its own transformation. In Ormerod's view companies are apparently essentially tossed about randomly on the sea of success and failure. Whilst for Senge, and Foster and Kaplan, companies create their own destiny through learning and knowledge. The papers presented here lead on to show that these views are not necessarily antagonistic and that complexity science can bridge that gap through modelling and understanding the nature of organisational co-evolution and industrial eco-systems.

1.14 Organisational learning

Learning in organisations is an issue that has been addressed since Weber (Dodgson, 93) and has been considered an important element in an organisation's capability to adapt (Senge, 90). There have been many attempts to give a definitive definition of organisational learning (Dodgson 1993, Weik and Westley 1996) but as both Weik and Westley, and Dodgson point out none has been totally successful. Weik and Westley in their overview article on organisational learning with Westley for the Handbook of Organization Studies (Weik and Westley 1996) puts forward the polemical contention that this is in part at least due to the fact that the term 'organisational learning' is an oxymoron. They point to a tension between the word organisation and the word learning. For them 'to organise is to forget, whilst to learn is to disorganise and increase variety'. They argue that the process of organising incorporates previous learning into a structure thereby excluding and 'forgetting' other possibilities, whilst the process of learning is to go beyond present structures to look at new ways and possibilities and thus, in essence, to disorganise. This leads to a fundamental dissonance between formal organisational structures and adaptability. Weik and Westley go on further to point this out and say that formal systems of organisation can lead to rigidity.

Information systems are by their nature formal systems (Avison et al., 1995) and therefore it would be expected that they could on occasion lead to rigidity and an inability to adapt. Indeed this has been shown in a number of studies. (Avison et al. 1995, Allen 1991, Fitzgerald 1990). PICT researcher Paul Quintas (1996:85-9) has even coined the term 'electronic concrete' to describe the results of this. IS can therefore be seen lead to a reduction in the capacity to adapt, and may be used as an example of how formal systems can lead to a lack of flexibility and adaptability.

Freedom Analysis (2005a) addresses this problem of formal systems by operationalising solutions to it in a systematic manner.

1.15 Learning and evolution

For Argyris and Schön (1978, p2) learning involves the detection and correction of error. A major way that organisations do this is by adapting to their environment (Senge, 1990); this maybe the external or the internal environment, or on occasion both. According to Senge when an organisation adapts to its environment it adjusts its behaviour in order to respond to the problems that are thrown up and in this way learns. It follows that if learning is to be planned for then planning for adaptability can play an important role and if so mechanisms for dealing with this will need to be in place already (2005a). To be a 'learning organisation' is not to be surprised by the unexpected but paradoxically to be prepared for it.

Following on from Weik and Westley's view of the tension between organising and learning mentioned above it can be inferred that the functionality of a system is its ability to deal with the expected; what it was organised for. This is composed of the processes within the organisation that are open, at least in theory, to being rational and deterministic. These are the functions of Taylor’s Scientific Management (1911) and later of Weber’s bureaucracies. On the other hand adaptability, and agility, are an organisation’s capacity to change and is choice driven and non-deterministic. For instance this can be due to changed circumstances, where the error that is detected is a new mismatch in the capability to deal with a changed environment. But there are other cases. There are a number of other situations where circumstances have not changed but organisations can learn from mismatches. Such as when the circumstances have not changed but the organisation's response is found to be erroneous. To purposively benefit from this the organisation must have the ability to see and recognise the mistakes when they have occurred and then the capability and willingness to respond to them in an appropriate manner (2001, 2005a). It must be able to 'learn from its mistakes'(2005d). Secondly there is the situation where the organisation's believes it responses are adequately matched to its circumstances but then finds a better way of delivering the same responses or of delivering refined ones (2005d). Again in order for this to be a purposive activity the organisation must be actively seeking ways in which it can improve its response delivery. It must be able to 'learn to do things better'.

The functionality of an organisation is its ability to deliver responses both externally to its environment and internally amongst its constituent parts and members, its ability to gain ‘sustenance’ from its environment and to deliver ‘sustenance’ to its constituent parts. Its adaptability is its ability to change or refine those responses, its agility is the rate at which it can make those changes. This can be as a means of coping with present and maybe changing circumstances, Senge's (1990) adaptive learning. But Senge also contrasts this with generative learning where this can be a more active forward-looking process by which the organisation creates the future, or in Fahey and Randall's memorable phrase is ‘learning from the future’ (1997). This is the process of innovation and evolution which is central to many of the submitted works. In either case if this is to be purposive the organisation must be actively engaged trying to find better responses, the organisation must build in the processes of adaptation.

Argyris and Schön (1978) talked of three types of learning, single loop learning, double loop learning and deutero learning. In single loop learning the response is changed, or possibly confirmed when it is experimental, but there is no change in the structures or routines of the organisation. It is therefore possible for the knowledge to be quite quickly forgotten. Whilst in double loop learning, the structures and routines are changed and the new knowledge is embedded, but the old knowledge maybe forgotten.

Deutero learning is the process of being actively engaged in the learning process, to reflect upon how and what the organisation learns and the processes by which it learns. It can be seen that Senge's generative learning and deutero learning are not the same but complementary. To be a truly forward-looking 'learning organisation' both will be needed. It will be necessary for the organisation to not only want to learn but have inbuilt the mechanisms by which it can learn. Amongst these mechanisms will be methods for embedding appropriate adaptability.

When Senge's adaptive learning is being considered it is clear that purposive learning takes place. That is when there is some deliberate response to an 'error'. But to deliberately respond the problem must first be known about or inferred and this can only be done if there is the appropriate type of information for the problem to be appraised. This information must some how be transmitted from the problem's initial location of inception to the location where it is to be solved. Further at the location where the problem is to be dealt with there can be no response if action is constrained with respect to the attributes of the problem; there must be freedom of action within the dimensions of those attributes.

Senge's idea of generative learning, on the other hand, implies that there maybe no present problem to solve; the problem is the future. But in order to anticipate future problems there must be sufficient information and knowledge to generate a picture of the future, a scenario, however vague and uncertain this may be. How to arrive at and deal with this scenario then becomes the 'problem'. These scenarios must then be transmitted to the locations where they can be dealt with. And again there must be the freedom of action to deal in the dimensions of their attributes. This can be a powerful way of ‘learning from the future'. HP's research labs provide an excellent example of the first part of this approach. There the researchers are tasked not to look at ways to improve the company’s products but instead to invent the products that will competitively replace them. By this invention of the future HP gained long term competitive advantage (Creel, 1994)

1.14 Overarching theme and areas of contribution

The overarching theme of the works presented here has been development of the modelling of organisational evolution and co-evolution from a complexity science perspective, and the understanding of the implications of this for organisations, organisational science and complexity science. This theme has been explored and implications have been found for both theory and practice.

This has been done mainly, but not exclusively, within the context of agility, adaptability, emergence and learning. One strand of these papers present a set of three distinct types of novel contribution. They are, in order of importance to the overall theme (but in reverse order of their causal logic):

(i) New findings and understandings of the processes and drivers of evolution in social systems and organisations and their implications.

(ii) New evolutionary models and frameworks of organisational evolution and its elements from a variety of points of view.

(iii) New developments in Evolutionary Complex Systems modelling and Complexity Science theory and practice.

A number of different approaches were developed and explored in the papers. One approach does this by showing the relevance to human social systems of the mathematics that was developed by Allen (1975, 1976) for the invadability of ecosystems. It is used to model the invadability and restructuring processes inherent in organisational evolution.

The second follows on from McCarthy et al (1997). It gives important new insights into the nature of the structuring processes in industries and markets. They used the classical evolutionary biology theory of cladistic analysis on the industrial landscape of practices within the automobile manufacturing industry to develop a cladistic tree of practices. Whilst this was a radical departure and gave useful information it was a static view. The submitted works take this on to develop, from further large scale survey work, a view that is both more dynamic and more predictive, and that also validates the original analysis.

The third approach was the development of dynamical and agent based Complex Systems models that could simulate, explore and illustrate various aspects of organisational evolution.

These developments lead to a coherent view of many of the aspects of organisational evolution that give insights into the mechanisms and constraints imposed on organisations as they evolve. And leads to insights for practitioners.

In addition there are four further contributions to modelling theory and practice:

1. The development of the pair interaction matrix and its use in a dynamical model to validate the development of a cladistic tree and show its possible other forms. Also its use in indicating the invadability and bifurcations of the

cladistic tree that would lead both to these other forms and those that it could take on in the future. This is detailed in the paper 'The Evolutionary Complexity of Social and Economic Systems: The Inevitability of Uncertainty and Surprise' (2003).

2. The theoretical concept of a structural attractor. This is an extension of the concept of attractor from dynamical systems theory. It is used in a number of the papers and the concept is developed in them.
3. The development of the theory of the Fundamental Model. This is used (a) to unify all model descriptions of a system, (b) as a step in the process of integrating sub-models into a coherent super-model, (c) to derive simplified models of the system that can be used to investigate qualities that either cannot be simulated or would be expensive to simulate fully, (d) as a formal bridge between formal models and qualitative descriptions (informal models). This is detailed in the paper 'An exploration of qualitative modelling within the IIAP'
4. The development of Freedom Analysis which leads on from the connectionist work detailed above. It was formulated in response to the question: What can be said about a system that is stressed beyond its known dynamic? It is a first attempt at the development of a "calculus of adaptability" in answer to Simon's (2001) suggested problem. It is detailed in the paper 'An exploration of qualitative modelling within the IIAP'

These innovations have been used to address the main questions and problems outlined previously for complex systems, both theory and modelling, for organisations and social systems. The overall question that is addressed in these works is:

How may we better understand organizational evolution and change?

And understanding is inevitably linked to the theories and models that we develop, based on complex systems thinking, to generate and capture the observed behaviour. The papers submitted here address this central question, doing so by discussing six more specific thematic questions which cover and draw together the topics of the papers as a whole. Each will be discussed in detail in the next section. The six questions have been selected for their overall contribution to the themes of the papers, their individual importance and the generality their scope. Three have answers that are mainly in theory development and three with answers mainly in complex systems modelling development and practice. The three mainly theory development questions are:

Q.1 How can models be categorised and can there be a simplified uniform and unifying method of describing models?

Q.2 When a system is open what can be said, in modelling terms, about it and how does a system deal with openness?

Q. 3 Are their semi-stable regimens in open evolving systems and how can they be characterised?

Whilst in complex systems modelling development and practice the three further questions addressed are:

Q. 4 How do learning and knowledge emerge in co-evolving systems and their models?

Q. 5 How does the evolution of markets and companies build the cladistic tree of an industrial eco-system, is the particular tree unique, and what does it tell us about the open future?

Q.6 When and how does innovation take place?

1.15 A map of the flow of some of the important influences within the papers

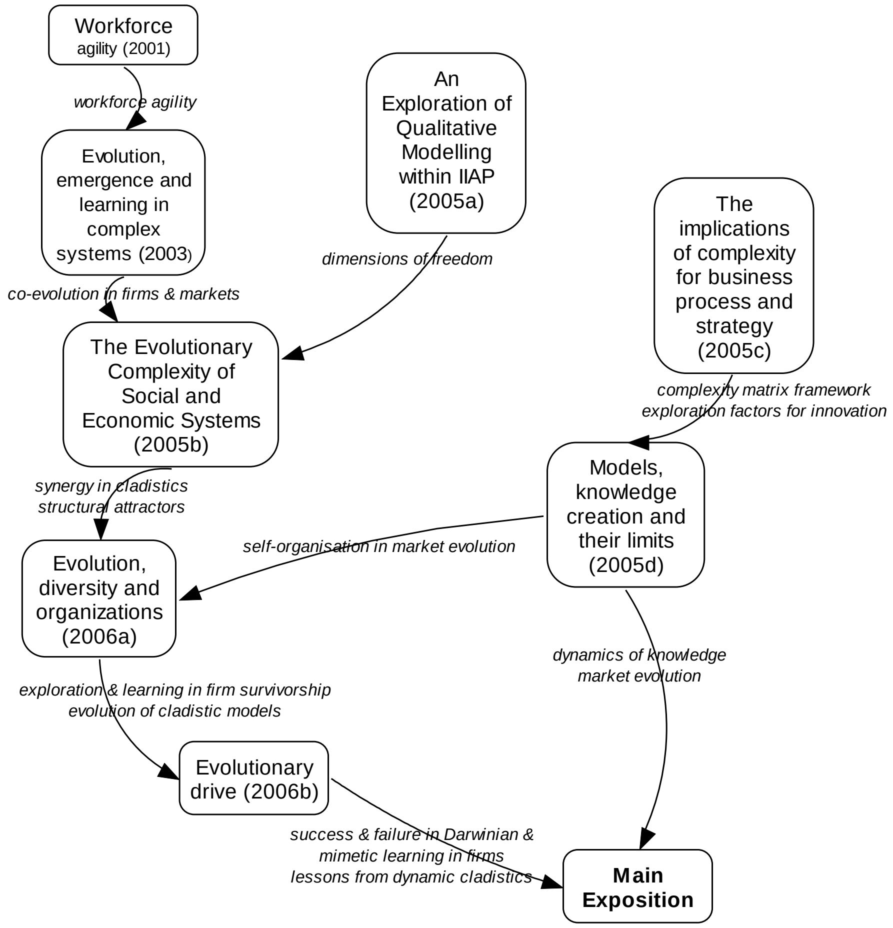


Figure 4 A map of the flow of some of the important influences within the papers

1.16 Table of Questions, Methods and Results

	Paper	Questions	Methods	Results
1	Workforce Agility (2001)	What attributes reported in the literature define workforce agility? How relevant are IS and the associated working models to workforce agility?	Literature review Survey and data analysis	Summary of agility attributes (table 1) Workforce agility indicator, capabilities of workforce agility (table 8)
2	Evolution, Emergence, and Learning in Complex Systems (2003)	How do learning and knowledge emerge in co-evolving systems. What practical implications does this have for : a) distribution networks, b) competitive strategies in markets	Evolutionary distribution model. Evolutionary market model	Co-evolution of distribution network with customer learning. Simulation method for distribution design Development of the evolutionary market model.
3	An Exploration of Qualitative Modelling within IIAP (2005a)	How can you model the future of a system stressed beyond its known dynamic? Is there a common basis for all modelling?	Theory development and argumentation Theory development and argumentation	Freedom Analysis Fundamental model
4	The Evolutionary Complexity of Social and Economic Systems: The Inevitability of Uncertainty and Surprise (2005b)	Modelling the effect of choice on the evolution of behaviour. How did the cladistic tree of industrial practices form? Was this the only possible cladistic tree? How to characterise stable regions in a complex evolving system.	'Policeman' model Development of synergy matrix Development of evolutionary practices model from synergy matrix. Argumentation	The 'rational' development of bias. Use of synergy matrix to explain complex structural development in industries. The discovery of alternate forms fro the cladistic tree Structural attractors

5	The implications of complexity for business process and strategy (2005c)	What implications do evolutionary models have for business process and strategy. What are the abuses of modelling? What factors are needed for successful exploration of innovation space?	Argumentation based on previous models.	Development of the complexity matrix framework. The two abuses of complex systems modelling. The importance of ignorance and other factors in exploring innovation space
6	Models, knowledge creation and their limits (2005d)	What are the principles controlling the structuration and evolution of markets?	Self-organising market model Evolving market model	The dynamic creation and destruction of knowledge within markets. The processes of self organisation within markets. The processes of evolution in markets
7	Evolution, diversity and organizations (2006b)	What factors lead to survival or failure of firms. What new practices can 'invade' a system of industrial practices?	Character space model. Evolutionary market model Dynamic extensions to cladistics model	The importance of exploration and learning to firm survivorship. The dynamics of evolution in cladistics models and its implications.
8	Evolutionary drive: New understandings of change in socio-economic systems (2006a)	The inclusion of micro-diversity as a driver for evolution in models. What sets of company strategies can profitably co-exist? What are the broad characteristics needed for a new practice to invade a system?	Extensions to the character space model. Extensions to evolutionary market model. Extensions to dynamic cladistic model	The success or failure of various mixes of Darwinian and mimetic exploration. The lessons from the dynamics of evolution of cladistics models.

2.0 Main Exposition - How the papers address the six questions

Broadly speaking in these papers an objectivist standpoint is taken. However one sub-theme of them is to look at the distinction between objectivist and qualitative viewpoints seeing how they in fact coexist in a kind of chicken and egg situation. The papers submitted contain a number of modelling efforts to move away from purely numerical models to those that use formal methods to model more qualitative data. This is perhaps most clearly seen in the development of the ideas of the fundamental model, and freedom analysis in 2005a and the extension to cladistic analysis with the development and application of the synergy / conflict matrix which is used in a number of the papers (i.e. 2005b, 2005c)

The main section discuses the submitted papers in terms of the questions posed above. Some of the questions are more pervasive than others with answers and discussion in a number, if not all, of the papers others only appear in one or two. The themes that recur go through a process of refinement from paper to paper so that the concepts involved evolve over time. Their final state in the papers is not the end of their journey but merely a stopping point along their pathway, the present end point of the cladistic tree of their development. The theoretical questions are dealt with first and the modelling ones after. In each section the papers are mainly dealt with chronologically to show the way that the ideas have developed over time, but not always. Some papers were published out of writing sequence and sometimes there are later refinements that better justify earlier conclusions. So because of this the papers and even the parts of papers, dealt with in reference to one question will often be referred to again when considering another one.

Q.1 How can models be categorised and can there be a simplified uniform method of describing models?

A useful development in these papers is the creation of what has been referred to as the ‘cloud diagram’, see Figure 4. It refers to a set of successive assumptions that are applied, consciously or subconsciously in modelling. Each additional assumption creates a new category of models that are simpler than the one before it. At each step the models become easier to handle and interpret and also need less data, but they are less realistic. In 2005b this is referred to as:

‘Let us consider carefully the successive assumptions that would be involved in building a mechanical representation of an ecosystem, an economic market, or an organisation, and what the meaning of these simplifications is. The assumptions are:

1. That we can put a boundary around some “system of concern”, and try to understand what it will do as a result of what is inside, and in the context of what is outside.

2. That we know how to classify the different types of interacting entities within the boundary, and therefore that we have an adequate “dictionary” of possible terms.

3. That we can consider the actual entities present currently, and through their dynamic interaction understand what may happen.

4. That we can consider the interactions in terms of their average values, smoothing what would otherwise be marked by irregularities due to their discrete and individual nature.’

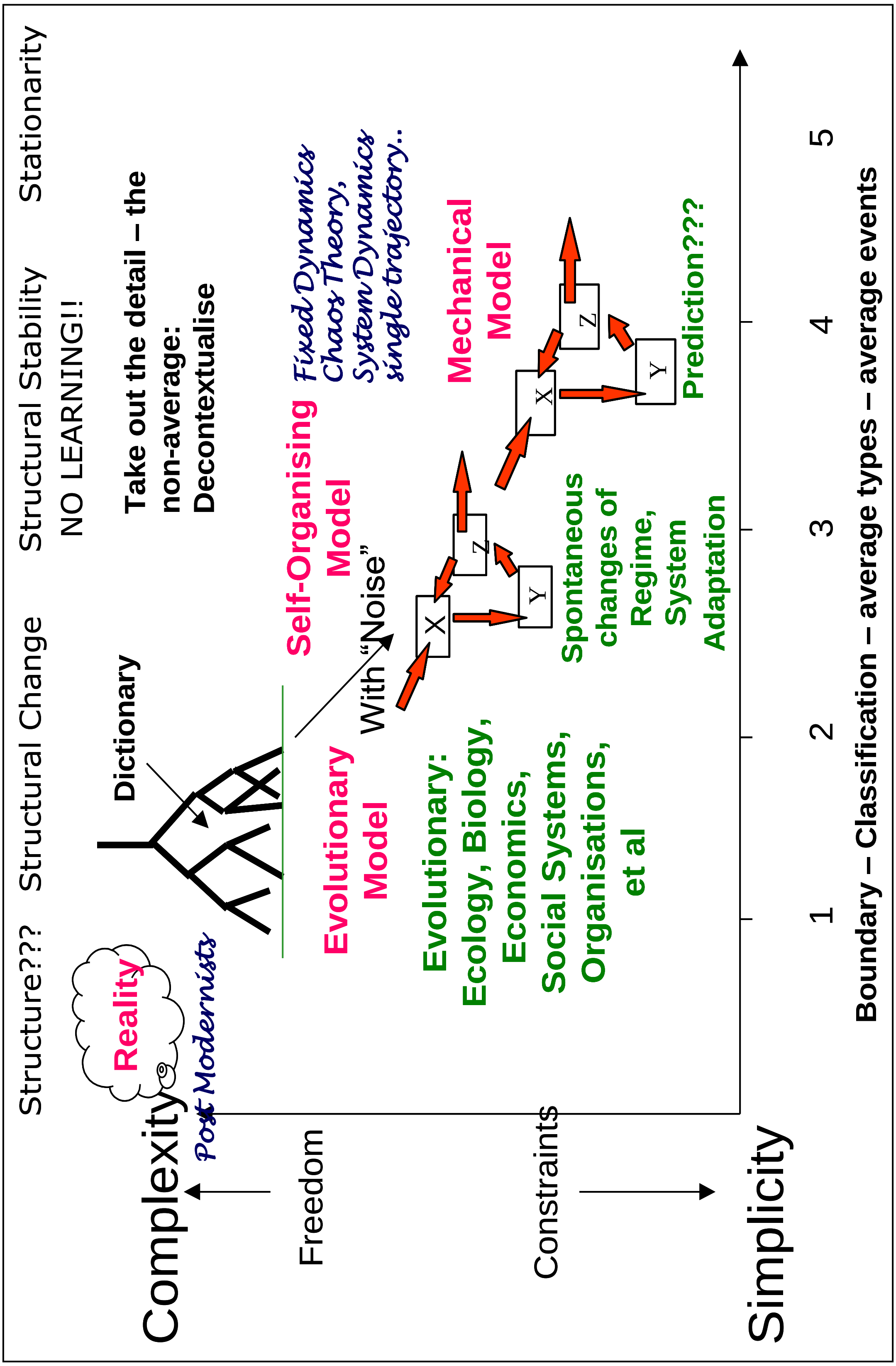


Figure 5 The cloud diagram (from 2005b p.2)

As can be seen in Figure 4, from 2005b, these simplifications lead to categories of models, and examples of each type are shown in the diagram. There is a further refinement in 2006b table 2 of this categorisation into a general complexity framework. However in 2005b each category is shown to have its uses, and when correctly applied can yield useful information. But each category moves further away from the cloud, reality, so that at each step the information it yields, although more easily obtained and interpreted, is more limited in scope, particularly temporal scope, and also often carries a greater possibility of being misleading. First, before any simplification, there is the 'cloud' representing underlying reality. Note however that even here, when talking of reality, an assumption has already been made and that is that there is some form of underlying objective reality to the world that we perceive, and that we each perceive this underlying reality similarly enough to be able to intelligibly communicate about it. In the diagram the first assumption step of a boundary is made to define the system under study and then that is broken into a set of named categories that are the so called dictionary of the system. We show how this level of assumption is commonly used when building models of an evolutionary nature, whether of technological, biological, economic, or social systems. A common example of this is the cladistic tree that was developed in evolutionary biology, and then discussed in management science by McKelvey (1982, 1994) and later applied to the industrial landscape by McCarthy, et al. (1995,1997). This has been further developed in these papers but these developments will be discussed later. Cladistic models show the emergence of new 'species' and describe the evolution of the system over time, with each successive branch splitting off at a bifurcation point and creating a new descriptor for the dictionary. They very clearly demonstrate the path dependence of the system and map the trajectories of the changing actors over time. Each new bifurcation creating newly differentiated actors and new dimensions of action in the system. This is discussed in (2005c:3) where it was commented that:

> 'If we assume that we can classify the elements within a system then we can map out its evolutionary history. In some ways there is a degree of "tautology" about this, because we have to assume that we know the key differences between elements so that it enables us to "make-sense" of its evolution – in terms of the constituents that we have ourselves defined. This is related to the idea that sense-making is an experimental process in which we are searching for self-consistency between the classification rules, and the sense that appears to result from their application. Hopefully, then, one obtains an "evolutionary tree" of some kind that captures the occurrence of innovations over time, leading to the current situation. The most obvious results of such a tree is that over time some things have disappeared, but more importantly various innovations have occurred -

> new entities and elements, providing new capabilities, attributes and properties for the system as a whole.'

The next category leads to models that are self organising. They show emergence through the noise in the system but play out the fixed dynamic of their unvarying categorisation. They are no longer able to show the long term evolution of the system with its surroundings and 2005c discuses this in some detail. 2006a in the same context goes on further to show how the noise of 'the micro-diversity that is constantly generated at a *low level* in a system leads to the evolution of structure.' But the evolution of new types, which in reality is inevitable in the long run, has in the model now been lost.

At each stage as more assumptions are made more of the wider temporal correspondence is lost. The picture of today, and maybe even its immediate surroundings, can be clearer but the picture of more distant times, both past and future is obscured. This is illustrated in 2005c with a new categorisation of models. Here the models are mapped onto a complexity matrix (2005c, Fig. 5) which has axes that vary from short term to long term on the x axis and from open to closed on the y axis and each quadrant is shown to have its own character. This is further refined in 2005c Figure 6 as an 'activity matrix' for a complex system with clear implications for the management of systems at all scales from nations to individuals. This idea is re-examined and extended in 2006b Figure 5. Here the x axis has become the continuum from operational to strategic management. And the lower left mechanical quadrant has been expanded to show that the concepts of epistemology, theory and model lie there.

There are other problems that arise due to the reduction in view caused by particular assumptions. As it is put in 2005b, Figure 2 'Different people see the same system in different ways. Each can however be rational and consistent, whilst implying different actions or policies' and later goes onto say: 'Rational improvement of internal structure, the traditional domain of "systems' thinking", supposes that the system has a purpose, and known measures of "performance" which can indicate the direction of improvements. But, this more fundamental structural evolution of complex systems that results from successive invasions of the system by new elements and entities, is characterized by emergent properties and effects, that lead to new attributes, purposes and performance measures.'

The categorisation of models is dealt with from another viewpoint in 2005a. This paper draws a difference between descriptive models and simulation models. It defines a descriptive model as a model that: ‘explains what something is from a particular point of view. It will therefore have some form of categorisation built into it but will not go on into the mechanisms involved’ and also points out that ‘all models rest at heart on descriptive modelling, as we shall see even a full causal simulation model rests on a series of descriptions.’ . It goes on to say that the ‘process of building a model is a process of choosing, and this is an act of judgement. So that though the model itself may be deterministic the fact of the model is not. The process of choosing decides what will be included and what excluded from the simulation. Whatever is transient, not invariant and diverse and so cannot be described in the fixed terms and categories of the model are excluded.’

In order to find a way to combine models, in however limited a fashion, 2005a proposes the concepts of the Fundamental Model (FM), a purely theoretical construct, and its derivative the fundamental model (fm). In the paper the Fundamental Model is defined:

> ‘The Fundamental Model (FM) of a system is a uniform set representation of all of the possible objects of a system and their relationships with each other, from all possible view points.’

Whilst

> ‘The fundamental model (fm) is a part of the Fundamental Model (FM). It is the system as seen from a particular view, or set of views, but expressed in the same uniform representation as the FM. It is the lowest level invariant of a particular view of the system. Any changes that affect the fundamental model will always have an impact on all higher models of the system from that viewpoint.’

The paper then goes on to show a number of ways that the fm can be used and extended in practical modelling that form new classes of models. First because the fm is a uniform representation and it can therefore be used to combine representations of different models, different types of model and models of different viewpoints. The paper then goes on to show how these new representations can be simply extended and used in a number of ways, such as sensitivity analysis and rapid approximation. It further develops a method of looking at an open system and how its openness can affect it in a new modelling technique called Freedom Analysis dealt with in more detail under the next question.

Q.2 When a system is open what can be said, in modelling terms, about it and how can a system deal with its openness?

In 2005a:7 Figure 2.5 and the explanation that goes with it simulation models are described in terms of a set of mapping functions and the validity of the model is decided by an error function. But when, as has been demonstrated in the discussion of Question 1, it is always the case that the model is only a partially complete view of an open system this validity will not hold indefinitely. This is even true of a purely descriptive model.

One view of the modelling process is that of 2005a where invariance is shown to be central to the process of modelling. In this view the model is created from the openness of reality by closing this openness with invariants. This is carried out through a process of mapping reality onto a set of invariants, i.e. categories, names, dynamics, etc. Also as 2005a:5 put it:

> Invariance is the fundamental core of modelling. A model is a reduced description of part of reality that conveys most of the information that is thought to be important for the particular view that is being considered. Within static descriptive modelling the invariants are the categories that the objects are assigned to, indeed the very act of saying that something is an object is already to have categorised it. In verbal descriptive models the categories are words and signs and are a part of the very language being used. Without words and signs description would be impossible.
>
> Where in static descriptive modelling there is one layer of description that of categorisation, in simulation modelling there are at least layers of description. First there are the variables of the system. These correspond directly to the categories of a purely descriptive model, and this can apply to some parameters as well. Second there is the dynamic of the system that is described via a mapping onto the model dynamics. Finally there is the initial state the simulation will start from.

2005a:5 goes on to point out when building models that:

> The process of building a model is a process of choosing, and this is an act of judgement. So that though the model itself may be deterministic the fact of the model is not. The process of choosing decides what will be included and what excluded from the simulation. Whatever is transient, not invariant and diverse and so cannot be described in the fixed terms and categories of the model are excluded. To overcome this the modeller uses parameters and averages to remove the diversity and to represent the microstructure and externalities of the system.
>
> So invariance is the bedrock of modelling because a model is constructed from a set of presumed invariants. What is external to the model, either at the macro or micro level, which turns the real open system, which is intractable and incommensurate because of its openness, into a closed, tractable and commensurable approximation. However the richness is lost and in the long run the model will fail as the system veers off its predicted course. The long term may not be of interest but more and more simulation models are being pressed into service to attempt to predict well past their foresight horizon [Lane 1996]

When it comes to modelling human systems there is also the dual problems of freewill (discussed above) and rationality which was pointed out in 2005a:2. Simon (1992) proposed his satisficing mechanism instead of full rationality to deal with this problem but even this is not wholly satisfactory in the form which he put forward, as this was still an optimal mechanism.

So if the world is inevitably open, can modelling say anything useful about it? It is the view set forth in these papers that it can, we do not stand with Wittgenstein’s (1992) statement "Whereof one cannot speak, thereof one must be silent". And we show three different approaches to this question that put forward our arguments for this. The first and most straight forward argument is given in terms of policy making in 2005a:9:

> Is simulation therefore useless? No, quite the opposite, simulation has become a part of, indeed often a driver of, the non-deterministic social system. Not as a predictive and deterministic tool but as a rational method for exploring possible futures. At best it allows the policy developer to see the consequences of possible choices and judgements before they

> are finally adopted, with all the contributory assumptions laid bare. This gives the policy developer powerful new tools that, whilst they do not predict the future, build from scenarios to show possible and likely outcomes under a wide range of assumptions. This allows him to peer, however darkly, further into the future and to learn from it.

This shows why the dynamical approaches and simulation models in most of the papers were developed. They help in understanding the mechanisms driving the part of the world that they describe, and hence their past and future trajectories for the time that their modelling invariants hold. This gives a useful understanding of the systems they describe about the point of their description.

The second approach is the application of cladistics and the new extensions to human systems. The cladistic model shown in 2005b Figure 8 shows how new practices can impact an industry's evolution. What cladistic models don't show is whether this was the only possible outcome and what is possible in the future 2005c explores these questions and will be discussed further in the discussion of question 5.

The third approach from these papers is the development of Freedom Analysis which is outlined in 2003: 24 -- 25. The most general question that Freedom Analysis addresses is 2005a:24: 'how much can we say about what is beyond the known?' This was elaborated in modelling terms in 2005a:24 as:

> The analysis can be broken down to three questions related to the level of change in the fundamental model:
>
> > If a system is stressed in such a way that it moves outside the scope of its known dynamic what can we say if the fundamental model
> >
> > (i) remains the same?
> >
> > (ii) changes but only in terms of changed relationships
> >
> > (iii) changes and the number of objects change?

The discussion in the paper (2005a:25) proposes an important principle that:

> When a system changes, for whatever reason, the stresses that cause the changes will impinge on the system at particular points and will have particular characteristics or dimensions. In the first instance then only those relationships within the system that have the

right dimension and lead from the stress points can start the pathways that transmit the stress through the system. Those relationships that are detailed in the fm but which also have the same dimensions as the stress can then become elements of the pathway for its transmission through the system to the objects that make it up. The objects can react in a number of different ways. A given object can react according to its specified dynamic and pass on the stress through its other relationships. However it may develop a new dynamic that adapts to the stress, transforms it, or dissipates it. Then it is said to have the 'freedom' to react to changes.

This implies a new modelling principle, the Freedom Principle:

> When a system is stressed outside its known dynamic it can only react, in the first instance, where both the imposed stresses are felt within the system and there is the freedom to act in the dimensions of the stress and at that level of stress.

The paper then goes on to discuss the other two cases in freedom analysis where similar conditions obtain.

These three approaches give three different ways to answer the initial question about what models can say concerning open systems and shows that whilst models cannot fully predict the effects of openness they can be helpful in indicating the latent possibilities.

Q. 3 Are their semi-stable regimens in open evolving systems and how can they be characterised?

In 2003:13 it points out that "Evolution in human systems is therefore a continual, imperfect learning process, spurred by the difference between expectation and experience, but rarely providing enough information for a complete understanding." But the important point is that this does not lead to total flux, Heraclitus saw this in 501BC when he wrote "We both step and do not step in the same rivers. We are and are not." although Simplicus characterised Heraclitus's teaching as 'panta rei', all is flux (Peters, 1967:178). He was called "Heraclitus the obscure" by succeeding philosophers, but his insights are still relevant today - and still obscure.

As was shown in the discussion of question 1 the process of modelling the world starts with bounding the system under consideration. This would not work if the bounding failed immediately because of a state of total flux, and the system, qua system, flew apart immediately. The discussion of question 2 shows the importance of invariants to modelling and these invariants must hold for the life of the model if it is to be valid, and total flux would not allow this. In 2006b:10, amongst others papers, emergence within models, even though they have fixed environments, is demonstrated with important results for the understanding of market and organisational structures.

However real environments are not fixed and models are merely depictions of embedded systems that have the coupled levels of description of the 2006a:29 Figure 1.21 version of the cloud diagram with three levels mapped on, these levels corresponds with Gillies' (2000) three pillars of complexity. This inevitable lack of a fixed environment, at whatever level, is a part of the cause of the failure of rationality. An example of the failure of immediate economic rationality is shown in the fishing model discussed in 2006b:l0, where:

> Running these fishery simulation models shows us that it is not true that fleets seeking profit with the highest possible economic rationality win. Indeed, the models show that it is important not to seek profit too ardently. Profit is actually generated by behaviour that does not seek profit maximally!
>
> This is because in order to fish for any length of time it will be necessary not only to exploit current information about fish stocks, but to generate new, currently unknown fish stocks, and exploit them. So exploitation alone is inadequate and some mix of exploration and exploitation are required… More importantly, we see that the knowledge generation of fleets arise from their ability and willingness to explore. So, instead of this corresponding to ultra efficiency and rationality, it actually arises from the opposite – a lower level of rationality, and a freedom to take creative action.

What happens in reality is not emergence of the eternal fixed attractors that pure mathematical models describe (Casti, 1992:112). But the emergence of semi-stable patterns that form the new concept, first put forward in these papers, of a structural attractor, which 2005b:12 describes:

> A structural attractor is the temporary emergence of a particular dynamical system of limited dimensions, from a much larger space of possible dynamical systems and dimensions. These are complex systems of interdependent behaviours whose attributes are on the whole synergetic…They correspond to the emergence of hypercycles in the work of Eigen and

> Schuster, 1979, but recognise the importance of emergent collective attributes and dimensions. The structural attractor (or complex system) that emerges results from the particular history of search and accident that has occurred and is characteristic of the particular patterns positive and negative interactions of the components that comprise it. In other words, a structural attractor is the emergence of a set of interacting factors that have mutually supportive, complementary attributes.

This concept gives form to a number of systems, i.e. in 2006b:15:

> Another example of these ideas is that the structural attractors, such as the market configurations and organizational forms of the sections above, can be seen in considering the research literature that ex presses how communities of researchers create, and evolve successive different structural attractors. In a study of medical research papers concerning the treatment of a particular form of heart disease, the literature of successive years in a particular domain has been analyzed, and the keywords and contents have been analyzed into different groups of research approach (Ramlogan, et al., 2006).

This concept of the structural attractor is a very general one which:

> …demonstrates the generality of the idea that evolution is all about the discovery and emergence of structural attractors corresponding to emergent capabilities and properties. It shows us that for a system in which we do not make the assumptions of average types and average behaviour (Allen, 1992) that would take out the natural micro-diversity and idiosyncrasy of real-life agents, actors, and objects, we automatically obtain the emergence of structural attractors... They have better performance than their homogeneous ancestors (initial states), but are less diverse than if all "possible" behaviours were present.
> 2003:29

Q. 4 How do learning and knowledge emerge in co-evolving systems and their models?

An important factor in the understanding of openness is knowledge. In 2003:9 this is demonstrated for evolutionary systems, in that paper it pointed out (2003:9):

The theory of evolutionary complex systems underlines the fact that there are really two kinds of knowledge:

- One is the traditional, classical type of knowledge concerning the physical laws of nature that are in no way affected by us knowing them. For example, Newton's law of gravity allowed all sorts of predictions and actions to be taken, but these laws themselves were not affected by this. They also appear to be (as far as we can tell) "eternal" and "unchanging," and therefore science could be seen as a process of knowledge accumulation.
- However, knowledge concerning people's behaviour, or the values placed on something, is changed by the "knowing." So either by communicating the knowledge or by taking action in response to it, the situation and the knowledge of that situation are changed. In human and social systems then, much knowledge is simply the internal cognitive patterns that have been generated linking stimulus to a person's particular response. As these patterns change and spread through the system, they undermine their own validity, requiring the regeneration of new patterns of stimulus and response. Subjective knowledge is only part of the evolution of the system.

This latter kind of knowledge makes all evolving systems open, and this is further demonstrated in 2003 through a model of the co-emergence of knowledge and structure in an evolving distribution network for photocopiers in the United Kingdom (see 2003, Figures 1 -- 3).

The modeller and the model also combine to form a co-evolving learning system and 2003:17 comments:"Here we see how building a model (even without actually running it) allows us to anticipate some of the real problems that would be faced by a participant in the real world." The paper goes on to give another example of this process in the case of an entrepreneur at start up (2003:17).

If we accept the definition of knowledge "as being something that structures possible action from random to highly defined, then clearly self-organization and evolution are creators of knowledge" (2003:29) then we can see that in the cladogram of 2005b:8 Figure 8 the organisational and industrial knowledge grows as the structure of the cladogram grows. This is not a purely random growth as the experiments with the 53 x 53 matrix in of 2006a:24 shows. A further important point is made in 2003 which goes on to show how the synergy of the system grows over time, as knowledge within the system grows (see 2003: Figures 9 – 11), this conclusion is reinforced in 2005c:17:

> Our results have already shown, Figure (12), that the evolution through the tree of forms corresponds to a gradual increase in overall “synergy”. That is, the more modern structures related to “lean” and to “agile” organisations contain more “positive” links and less “negative” links per unit than the ancient craft systems and also the mass-producing side of the tree. In future research we shall also see how many different structures could have emerged and start to reflect on what new practices and innovations may be available today for the future.

. One of the main drivers of this growth is the interplay of the processes that created micro-diversity, and the selection operated by the differential dynamics that recurs in the system and there is no end to this process of learning through “innovations and qualitative changes”:

> “Each behavioural type is in interaction with others, and therefore evolutionary improvements may lead to greater synergy or conflict between behaviours, and in turn lead to a chain of responses without any obvious end. And if there is no end, then the most that can be said of the behaviour of any particular individual or population is that its continued existence proves only that it is, and has been, sufficiently effective – but not that it is optimal.”
> 2006b:2

Micro-diversity plays a vital part in these processes of building the system and the mathematical development of this is shown in 2006b:3-6.

At the early stages of a new industrial sector 2006a demonstrates using ideas built from Hirooka's (2006) diagram, 2006a Figure 4, how innovations in organisations using exploration, learning and knowledge acquisition take place through the bundling of small micro-diverse innovations to make more significant innovative products. As the sector matures the micro-diversity is squeezed out and less exploratory, but more exploitative behaviour takes over.

This behaviour is illustrated in 2006b Figure 5, where it is mapped onto the complexity matrix initially introduced in 2005c Figure 5, but it now has arrows. These show the movement forward in time in one direction producing new realities and innovations whilst there is always a drive, particularly in the later stages of the development of the industrial landscape, towards exploitative behaviour and this grows with time and is indicated by the other arrow.

In open organisational systems this process of experimentation, learning and knowledge acquisition in co-evolving firms leads to the emergent market structures described in 2006b:10, and ultimately through the synergetic interactions of the 53 manufacturing characteristics of Figure 8 to the 16 organisational forms, page 13, through the cladistic processes illustrated in Figure 14.

Q. 5 How does the evolution of markets and companies build the cladistic tree of an industrial eco-system, is the particular tree unique, and what does it tell us about the open future?

Organisations evolve and die through a series of co-evolutionary processes with their environment (2006b). One of the important characteristics that measures the ability to survive is their adaptability (Foster, 2001). One of the prerequisites to being adaptable organisations has been found to be adaptable and agile workforces (Van Oyen, 2001). In 2001 we use Huang's (1999) definition of agility, it is: "an organization-wide capability to respond rapidly to market changes and to cope flexibly with unexpected change in order to survive unprecedented threats from the business environment". This paper goes on to discover the attributes of agility from a survey and literature search, 2001:23, and the components of agility via a principal component analysis of the survey 2001:26 tables 5 to 7.

However an organisation's survival depends in part on its ability to understand its environment and choices:

> The questions that any individual or organization wants to address are how best to update their understanding of the world around them, and how to relate their desires for success and prosperity to their possible strategies, policies, and actions. It is important to stress the "possible" because it essentially moves us into the future, and into the domain of prediction and predictive knowledge. What we want to know is fourfold:
>
> - What possible options do I have?
> - What might be the outcomes of these?
> - What are my criteria of preference?
> - Which possible choice is therefore preferable?

2003:10

This is illustrated by:

> The evolutionary model of Figure 5 has a kind of “Darwinian” evolutionary mechanism that allows entrepreneurs to explore the “possibility space” for products of this kind. The payoff achieved by any one firm or entrepreneur depends on the strategy (product quality and mark-up) used by the other entrepreneurs present. (2003:19)

One of the significant demonstrations of this model is that it shows how bankruptcies shape markets. For instance in 2003: 21 from the model of firms competing in strategy space: “We see that the number of bankruptcies “required” to shape the market varies for the different runs. For the “Darwinian” strategy of Figure 5 it is five up to this point, and for Figures 6, 7, and 8 it is four, six, and four respectively.”

But does this mean that firms in order to avoid bankruptcy should shun risk and "imitate whoever is making the most profit" (2003: 21). This same paper demonstrates that this is not the answer, because the model shows us that all firms would move towards the same place, and in so doing increase the degree of competition (2003: 22), leading to greater bankruptcies. This leads to the conclusion that “what might have seemed a “risk-averse” strategy turns out to be the opposite! To imitate in a market of imitators is highly risky.” (2003: 22).

So what overall strategies are best? Well this particular model set up showed that Darwinian random selection generally does worse than a learning hill climbing strategy, which is normally best. However with the important caveat that luck is really significant as chance still allows a great variation in market structures to emerge some favourable some very unfavourable. Here there is a complex interplay of responsibilities and reactions in markets that cannot be caught in simple optimising models. See 2003:16, particularly, Figure 4.1, for how even a very simple system picture can hide complicated behaviour.

In 2005d: 733 this model is again used but this time to illustrate how self organisation of firms leads to a market structure through the interaction of strategies. And 2005d: 736 introduces a new model of firms exploring product space which goes on to show how market exploration and exploitation tends to grow the average fitness of firms within the market.

This process mimics the evolved diversity of natural ecosystems described in 2006a: 2f. Where it is shown how natural systems build ecosystems through the synergetic exploitation of resources by multiple species (2006a:4 Figures 1 and 2) this demonstrates how the diversity of Darwin's finches evolved on the Galapagos Islands (2006a:8f). This process of exploration through micro-diversity is modelled in 2006a: 10. This model also shows the important lesson that the "explorer (species or organisation) wins the (fitness) 'climb' but loses when fitness cannot be improved." 2006b:17 lists some key points about evolution derived from all these models, amongst which are:

- Evolution is driven by the noise to which it leads.
- Evolutionary drive results from noise and micro-diversity generated at lower levels.
- This mechanism selects for the systems with noise and micro-of the micro-diversity generation.
- Therefore aggregate descriptions or categories will always be short-term.
- Successful management must be long-term and mimic evolution and incorporate exploitation, exploration and experiment.
- Structural attractors correspond to the emergent clusters: for products it is bundled technologies; for markets it is certain bundles of co-evolving firms: for organisations it is co-evolving practices and techniques.
- In traditional natural science a new theory must be falsifiable. In complex systems, particularly human systems, clean predictions are no longer possible and the criteria are less severe. Emergent structural attractors can occur just because there is a demand for their capabilities: fashion, lifestyles, art, communities of practice, etc. They are only concerned with whether there is a market for them, not with being true or false.
- Living systems create a multilevel world of co-evolve structures which evolve and change over time.

In 2006b Figure 7, adapted from Hirooka (2006), it shows how the micro-diversity of new core technological innovations lead to the formation of synergetic systems of products, which in turn lead to an ecosystem of industrial companies. As demonstrated earlier, such systems are vibrant and exploratory in their early stages (2003:22) "what really matters is that there should be real micro-diversity such that whatever happens, there will be a diverse set of strategies being played out in the collective system" then as failures and takeovers shape the industrial landscape (2003:22) the mature players become exploiters rather than explorers (2003:22).

This process necessarily leads to the discovery of new industrial products and practices (2005d:738) and inter-practice synergies and conflicts (2005c:15) which lead on to bifurcations that build the cladistic tree of the industry (2005b:11)

In 2006a:23 it shows how the synergies and conflicts can be formed into a matrix. And, as has also been shown earlier, that each new practice that can successfully ‘invade’ the system there will tend to be an increase in the synergy of the parts it associates with. Using this fact allows a probabilistic model to be built that explores the possible cladistic trees and industrial landscapes for a given industrial eco-system and find the likelihood of alternative histories, not just the extant one which itself is an example caused by the accidents and choices of the history of the system. Using this methodology we can explore how the system was built, and to some degree why. We can pinpoint reasons why particular historical innovations took off in one part of the system but failed in others

Leading on from this and of more everyday practioner interest is the fact that any new practice can only take off if it increases the synergy of the practices that it is combining with (2005c:10). So measuring any new practice against the synergy / conflict matrices of the organisational forms present in the landscape will show which organisational forms would benefit from taking up the practice and which should reject it and what kind of advantage it is likely to give to those who can usefully adopt it. Conversely, it is also possible to build a set of matrices from the conflict/synergy of any particular organisational form, and also the extracted matrices of the desirable or allowable attributes. It is now possible using this set of matrices to construct a matrix of the synergy/conflicts allowable for any new practice that it would need if it were to enhance the organisation introducing it, and vice versa, what attributes the organisation should avoid in any new practices.

Q.6 When and how does innovation take place?

True innovation is very difficult to study. In 2003:11 it says: “the traditional answer really has been by trial and error.” But this assumes a random process, Richard Dawkins "Blind Watchmaker" (1991). Another traditional approach is to hill climb to try to find an optimum (2006:17). And finally a third way is to try to make intelligent guesses as it is put in 2003:26:

> In reality, each agent in a social or economic network tries to make choices that are “better than random,” and no CEO could be seen flipping a coin in order to resolve some strategic choice. This is the essence of knowledge: an interpretive framework that enables us to make a “better than random” choice.

This is summarised in Figure 5

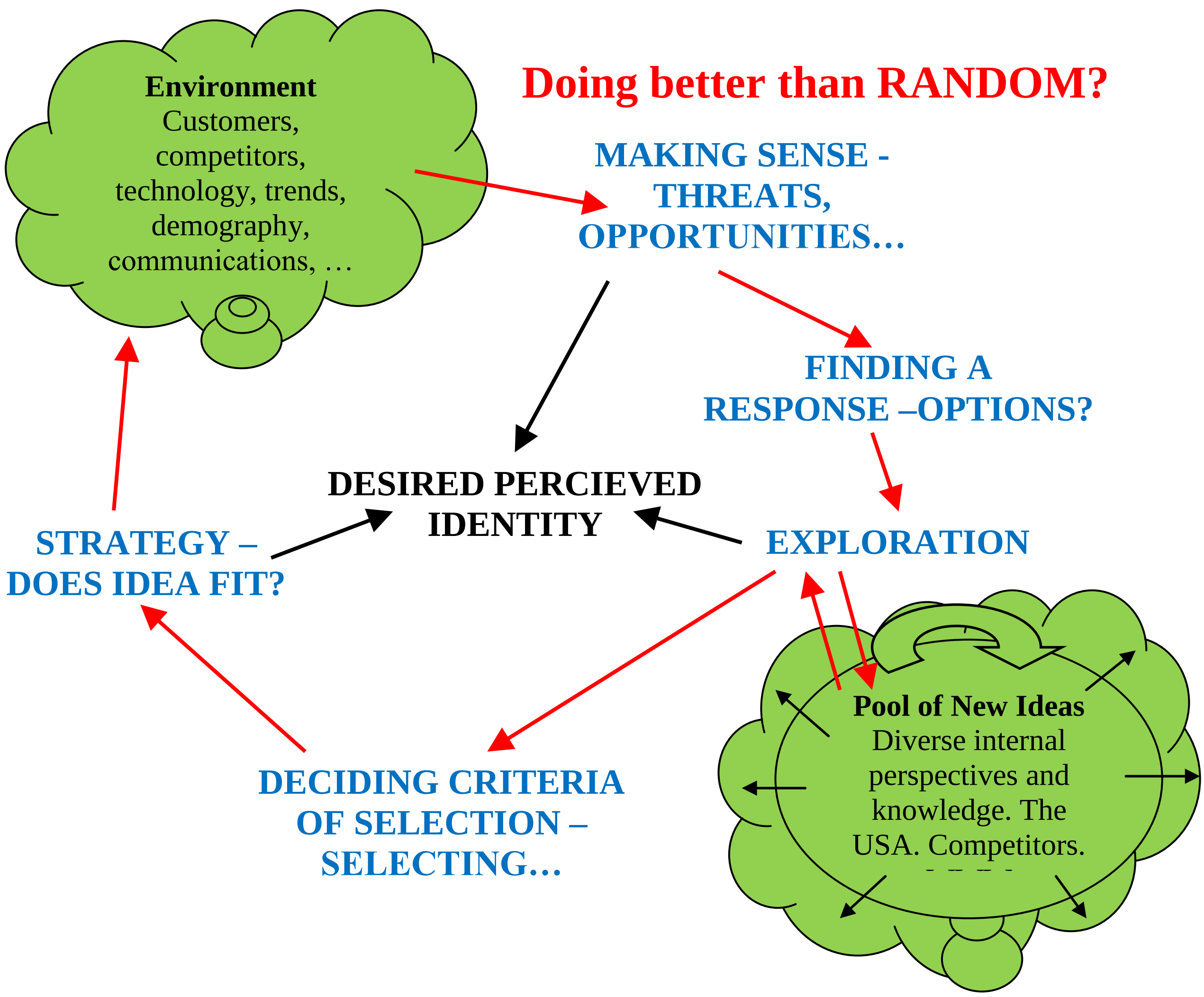


Figure 6 The clouds and arrows constitute an attempt to guide the innovations that are actually launched into the environment from an initially random selection. The desired perceived identity is really the firm's current strategy. (based on 2003:27)

In 2005a there is the concept of Freedom Analysis. Whilst innovation is not directly discussed as such, stress outside the known dynamic of the system may be an innovation or maybe the cause of an innovation. The act of freedom outside the known dynamic that adapts the system to the new situation, or maybe the act that causes the innovation. This allows freedom analysis to be used to pinpoint possible locations of innovation and say something about the dimensions of any possible innovation. But true innovations often break symmetry (reference) and introduced new dimensions. The breakdown of one structural attractor and the emergence of a new one, for as has been said earlier. "A structural attractor is the temporary emergence of a particular dynamical system of limited dimensions, from a much larger space of possible dynamical systems and dimensions. These are complex systems of interdependent behaviours whose attributes are on the whole synergetic."

This process is set in a wider context by paper 2005c:5 Figure 6 in the foresight quadrant of the complexity matrix. This is where "we have the sense makers and research department thinking about the history." And "this lower right quadrant is really the place where an initially open set of possibilities is turned into concrete innovations and developments, and these passed on to become a short-term reality. Clearly, one could also reflect on new designs and processes that decreased the ‘contingency’ requirements by being inherently less vulnerable to particular dangers ". (2005c:8)

Innovation is an uncertain, unpredictable and ambiguous phenomenon. However much we may try to reduce it to a process or formula. But "it is because systems can evolve and transform themselves that we can have hopes and dreams of better things" (2005d:730). In the model described in 2005d:732f firms co-evolve new strategies and products.

> They may simply try a new strategy of the same type, but more interestingly, they may move into new dimensions, bringing new attributes and factors into the game. … These simple evolutionary models show us how resilient strategies will emerge from such systems and in the case of particular market sectors suggest how the rules of learning can also evolve. In other words, by testing out firms with different rates and types of response mechanism, we can move towards understanding not only of the emergent ‘behavioural rules’ for firms, but also the rules about ‘how to learn’ these rules. That is, how much to experiment and with which parameters and whether any new dimensions of attribute space can be invaded "(2005d:724).

This is an important problem with innovation, how many resources should be expended on it. Too much is wasteful, and puts the organisation at a competitive disadvantage through the over expenditure of its limited resources, too little also puts the organisation at a competitive evolutionary disadvantage as it will get left behind by those who have more innovation.

> So, evolution will be driven by the amount of diversity generation to which it leads. Evolution selects for an appropriate capacity to evolve, and this will be governed by the balance between the costs of experimental ‘failures’ (the non-viable individuals created) and the improved performance capabilities discovered by the exploration. This is what holds ‘total diversity generation’ in check.
> (2006b:7)

In order to understand the phenomenon of innovation, it is also necessary to grasp the concept of invadability. For any new innovation must be able to acquire sufficient resources from its surroundings to at least maintain itself. Based on previous work by Allen (1976), the mathematics of this is discussed in 2006b:24, which shows how "we can use the evolutionary criterion discussed above to examine what new behaviours can invade the system"(2006a:6).

The details of the mathematics of this is laid out in 2006a:2ff. "Some partial confirmation of this … has been obtained. It concerns ‘Darwin’s Finches’ which inhabit the Galapagos Islands and which have been the subject of several careful investigations over the years" (2006a:8). This mathematics has been used to explain the innovations in beaks in the population of Darwin's finches, see 2006a Figure 1.5 and table 1.1.

The model developed in 2006a:14f embodies these ideas and the various runs of the model "demonstrate theoretically how micro-diversity in character space, tentative trials of novel concepts and activities, will lead to emergent objects and systems. However, it is still true that we cannot predict what they will be. Mathematically we can always solve a given set of equations to find the values of the variables for an optimal performance. But we do not know which variables will be present, as we do not know what new ‘concept’ may lead to a new structural attractor, and therefore we do not know which equations to solve or optimize" (2006a:21).

This leads on in 2006b to ideas using the results of Hirooka's (2006) research into innovation. Hirooka's diagram (2006b:7) shows how the non-average micro-diversity of new core technologies are bundled together to make the innovations of new possible products that in turn help to build the industrial landscape the “tentative trials of novel concepts and activities”. This is the problem with innovation the bundling together of new core technologies leads to new products with new, emergent properties, and maybe even new dimensions and structural attractors. It is only after "tentative trials of novel concepts and activities" that we will find out if the product will take off or not. From this we can see that innovations are driven by the competitiveness and micro-diversity of their environment. This micro-diversity is non-average, and so evolution and innovation is always driven by the tails of the distribution not by the mean. Future innovation and evolution, therefore, is driven by the small and uncertain and by historical accident, not by the average or large and predictable, they can only continue the past.

3.0 Conclusion

The papers presented have through the development of complex systems modelling and theory given answers to the six specific questions laid out in the section on overarching themes and areas of contribution. The answers are not definitive, nor could they be with questions of this nature, evolution is an ongoing process which can tear up old knowledge and build new knowledge, akin to Schumpeter's (1939) waves of creative destruction in economics.

Question 1 was about the categorisation and description of models. And a number of points of view from the papers were shown to address this. Starting with categorisation of models based on a set of general assumptions made by the modeller that formed the model's into a modelling hierarchy. Another category from 2003 is then given, the split between descriptive and simulation models, and this is used to lead-in to the idea of a fundamental model and its derivatives which are an attempt to form a baseline description for all models.

Question 2 was about open systems, what can be said about them and how openness can be dealt with. The papers demonstrated that all systems in reality are open as they are embedded in an open evolving universe, whilst all models are closed through the use of invariants chosen to represent aspects in the real world that in fact would normally evolve. A number of ways of working with models were then illustrated from the papers that illuminated particular aspects of openness. Some of the models within the papers show the dynamics of co-evolution of organisations. A separate view, that of the cladistic model and its derivatives, shows the actual evolution of an ecological landscape, in this case an industrial landscape. The papers also show how the mathematics of invadability developed by Allen (1976) can be applied to the cladistic evolution of industries. A further way to look at openness is described in the development of freedom analysis (2003) which looked at the problem of openness from the inside of a system.

Question 3 was about semi-stable regions in evolving systems and how they can be characterised. It was answered by first showing that there are semi-stable regimens and that without them description and modelling would not be possible. Then the papers show how the stable regions were categorised as "structural attractors", a new development derived from the mathematical construct of an attractor, but used to describe open and ill defined systems. Structural attractors were shown to be the product of synergetic attributes with positive feedback, and form the basis of complex systems models.

These structural attractors are not permanent features they change or decay over time. As they exist in the real world they are subject to the inexorability of the Second Law of Thermodynamics and are therefore dissipative structures (Prigogine, 1955). Prigogine showed how non-equilibrium dissipative systems could structure and form stable regimens and patterns that lasted for as long as the flows of sustaining energy and / or matter were maintained. As shown in 2003:29, 2005b:12 and 2006b:15 structural attractors last for only a limited period of time as one dynamical systems changes to another. They can therefore be usefully modelled as attractors, which are by definition not transitory (Casti, 1992a:112), if the time scale of the model is below the time frame in which the system remains stable. Attractors also cannot model the system close to or across the boundaries of change and instability when one system will become another.

The equilibrium of a system is then an attractor of the system; a point attractor is a static equilibrium and a cycle attractor corresponds to the idea of a dynamic equilibrium, such as Schumpeter's (1939) Walrasian description of how business cycles form, before taking into account the effects of entrepreneurship, which he showed throws the system out of equilibrium.

Structural attractors therefore are real world descriptions of systems that have a limited life and are in that sense transitory. Such systems are inevitably open and therefore subject to exogenous shocks and micro-diversity which leads to new structural attractors forming and in doing so often discovering or creating new dimensions of action. In as much as a structural attractor has stability for some length of time it can be modelled by closing the system both to the outside world and to inner micro-diversity and then using the mathematics of dynamical systems and attractors to give useful information. However this project will fail if the transition speed of the system is shorter than the period of study, or if the period of study crosses or lies too close to one of the temporal bounds.

Structural attractors approximate their theoretical counterparts, attractors, for much of the time and can be legitimately modelled by them, but in the region where one structural attractor fails and new ones are formed a system opens up and the mathematics of attractors is no longer helpful, indeed it hinders. Such systems show a greater similarity to phase changes in physical systems where an extreme sensitivity can be observed and transient effects can dominate whilst the system transitions from one state to the next. This is described by a different set of ill understood mathematics where there is apparent randomness, and action over large non local distances, the Butterfly Effect dominates. This is an area where systems are highly sensitive and, for instance, the defaulting on a relatively small number of mortgages in California can trigger a phase change in the global flow of money from liquid, with the money flow flowing freely, to solid, and little if any flow, leading to the virtual bankruptcies of nations.

Question 4 was about the emergence of learning and knowledge in co-evolving systems and it was answered by first showing that there were two types of knowledge. The first was scientific, Popperian knowledge based on an assumption of unchanging laws that can be built on and refined endlessly. The second was evolutionary knowledge based on evolving human behaviour, systems and structural attractors, what might be called "Schumperterian" knowledge. It is this kind of knowledge that makes human systems ultimately so intractable and particularly shows in their openness. A number of models were then reported on from the papers that showed three key aspects of the emergence of learning and knowledge. The first was the way that the evolution of knowledge as seen in industrial practices structures the industrial landscape through a process where synergy probabilistically increases. The second aspect was to show how micro-diversity was the key process underlying this process of learning and knowledge building. And the third aspect was to use Hirooka's (2006) work to illustrate how from this micro-diversity of knowledge at a lower level new innovations and knowledge diversity are built at a higher level.

Again this idea of the difference between Popperian knowledge and Schumperterian knowledge is a key understanding that permeates the submitted works. Popper in his 1934 work the "Logic of Scientific Discovery" put forward the view that true scientific knowledge was validated through the potential for falsifiability and could be demarked from pseudo-science by this. In a later work (Popper, 1994) he states this most clearly in his equation for the evolution of scientific knowledge:

$$PS_1 \dashrightarrow TT_1 \dashrightarrow EE_1 \dashrightarrow PS_2$$

Where a problem situation (PS_1) gives rise to a number of competing tentative theories (TT) which are then submitted to falsifiability criteria. This leads to the elimination (EE_1) and the survival, a la Darwinian evolution, of the fittest truth. And finally goes forward to a new and in his view more interesting problem situation (PS_2). Popper's (1972) view is that there is an objective world about which science has objective knowledge, that whilst it is not the truth it is similar to the truth and has an idealist existence in his World Three, the realm of the body of human knowledge.

In this sense Popperian knowledge is knowledge about a positivist eternal truth, the knowledge is not the truth, but through a process of evolution described above it evolves towards the truth which acts as some kind of goal function. This is a view of knowledge taken from the stand of an external, unbiased observer of a set of unchanging, eternal laws -- it might be approximated by physics but is difficult to reconcile with knowledge which is garnered from within an evolving system such as biology or a socio-economic system.

Popper was not without his critics the most influential of which was Kuhn who in his structure of scientific revolutions (1962) put forward the view that scientific knowledge was framed by the current scientific paradigm and that the latter was a sociological construction of the scientific community. Lakatos (1976) rejected Kuhn's stance but held rather that the unit of science was not the single hypothesis of Popper but rather it was the research programme in which there is a hardcore of theory with a protective belt of auxiliary assumptions and a heuristic. Heuristics are for him a '"powerful problem solving machinery, which with the help of sophisticated mathematical techniques, digests anomalies and even turns them into positive evidence." (Lakatos, 1976:5).

Another of Popper's students, Feyerabend(1975), in an iconoclastic lecture entitled “How to Defend Society Against Science” given from his standpoint of epistemological anarchism pronounced a plague on all their houses and radically criticised all their points of view. A major reason for this was that he felt their viewpoints led to a form of scientific fundamentalism akin to religious fundamentalism. Of Popper's stance he said "Popper's criteria are clear, unambiguous, precisely formulated..... This would be an advantage if science itself were clear, unambiguous, and precisely formulated. Fortunately, it is not." Kuhn's views he dismissed as "much too vague to give rise to anything but lots of hot air." and "wherever one tries to make Kuhn's ideas more definite one finds that they are false". Of his erstwhile colleague Lakatos, whilst being "immeasurably more sophisticated than Kuhn", Feyerabend felt that he "offers words which sound like the elements of a methodology; he does not offer a methodology. There is no method according to the most advanced and sophisticated methodology in existence today."

The phrase Schumperterian knowledge has been coined to refer to knowledge about evolving systems from a standpoint that is within the system and therefore contrasts with the use of the phrase Popperian knowledge which stands for a gradually refining knowledge about a fixed system from the standpoint of a neutral and rational observer. Schumpeter in “Capitalism, Socialism and Democracy” (1942 p.82f) explains:

> "Capitalism, then, is by nature a form or method of economic change and not only never is but never can be stationary. And this evolutionary character of the capitalist process is not merely due to the fact that economic life goes on in a social and natural environment which changes and by its change alters the data of economic action;"

And later goes on to say:

> "the laborer's budget, say from 1760 to 1940, did not simply grow on unchanging lines but they underwent a process of qualitative change. Similarly, the history of the productive apparatus of a typical farm, from the beginnings of the rationalization of crop rotation, plowing and fattening to the mechanized thing of today–linking up with elevators and railroads–is a history of revolutions. So is the history of the productive apparatus of the iron and steel industry from the charcoal furnace to our own type of furnace, or the history of the

> apparatus of power production from the overshot water wheel to the modern power plant, or the history of transportation from the mailcoach to the airplane... This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in"

Through this evolutionary process knowledge is also transformed and reborn by the blowing of the gales of creative destruction, for in evolving systems, especially for those within the system, knowledge must go through a process of evolution and rebuilding as the system itself evolves. Hence it is the very nature of competitive, evolving systems that gives rise to an evolving knowledge within the system.

This is the kind of knowledge that is obtained from a system embedded within a structural attractor. It may be possible to refine knowledge by some form of Popperian falsification process but the very truth about which the knowledge is held is itself evolving. For Schumpeter it is not the fixed, old type of equilibrium "competition which counts but the competition from the new commodity, the new technology, the new source of supply, the new type of organization". This is the process which drives the system from one structural attractor to the next and in so doing dismembers the old knowledge, discards some bits, rearranges others and combines them with new knowledge to build the new truths of the next structural attractor. Here knowledge is therefore forged in a Schumperterian gale of destruction and is, and can only be, changed from one structural attractor epoch to the next. This is not the Popperian knowledge of gradual refinement towards an undying truth; it is the essentially creative knowledge of evolution and survival born again and again in the dynamics of competition and survival.

Question 5 was about how the evolution of markets and companies builds a cladistic tree of the industrial landscape. This question was answered initially by addressing the attribute of agility, which has been found necessary for successful adaptation and evolution. It was then demonstrated from the papers how organisations' survival depended in part on the understanding of their environment, and how non-survival in the form of bankruptcies shaped markets. It also showed how what had appeared to be purely rational behaviour did not lead to greater survival chances. Models were then used to demonstrate how this exploration and exploitation shaped the industrial landscape. This was shown to be akin to natural evolution and natural selection and some lessons about micro-diversity and evolution in human systems were drawn. This led to a further discussion of micro-diversity to show how an industrial landscape evolves and builds on the cladistic tree of its ecosystem, the traces in the sand of its history. However it was then concluded that this history although itself unique was partially accidental and that other histories and forms could have emerged if different choices had been made. The synergy matrix used in modelling this was then shown to be useful in assessing possible future innovations.

Question 6 was about how and when innovation takes place. This was answered by first considering ways of looking at innovation and various aspects of it, showing how uncertain and unpredictable it is. But also showing how attempts to guide and locate it can be made. The question of the resources needed for innovation was mentioned before looking at the implications of the mathematics of invadability from evolutionary biology. This led on to how micro-diversity in new elements leads to new innovative products and structural attractors built from them.

We now come to three concluding issues. The first is how the papers have addressed the overall question of how we may better understand organisational evolution and change. These papers present insights on this matter from two different perspectives, one from within the organisation, and the other from the environment of the organisation. From within the organisation the papers looked at agility (2001), building in adaptability (2005a), the process of choosing better than randomly (2003, 2005d), building strategy (2005c) and which new innovations and practices can invade and will have positive or negative synergies for the company (2005b,c&d, 2006a&b).

From the perspective of the environment of the organisation the papers looked at a co-evolution of firms in markets (2005b&d), the evolution of industries (2005b,c&d, 2006a&b), invadability and synergy in markets and industries (2005d, 2006a), and how to model change, evolution and learning in organisations, markets and industries (2005b,c&d, 2006a&b). This demonstrates how the question was answered both from the point of view of the individual organisation and from the level of the market or industry that the individual organisation is involved in.

This brings us to the question of the difference between the views of Ormerod and Senge (amongst others). There are two points to note to start with. The first is that Ormerod's view is drawn from models built to emulate over a large database of companies whilst Senge is talking about individual companies. The second point is the biological sciences shown that the vast majority of species that have ever existed on Earth and now extinct (Benton, 1995). Because Ormerod's database was so large it is not unreasonable to assume that in many ways the deaths in it may be dominated by 'extinction' events at the industry cladistic level. If we now look at the papers and the work on cladistic analysis we can see the branches of an industry extant today. But what the cladistic tree does not show is how many branches have died out. However we can infer from an analogy with biological evolution that more industries and industrial forms have died out than are in existence now. If a company is in an industry when its industrial branch dies out there is no amount of learning that can save it.

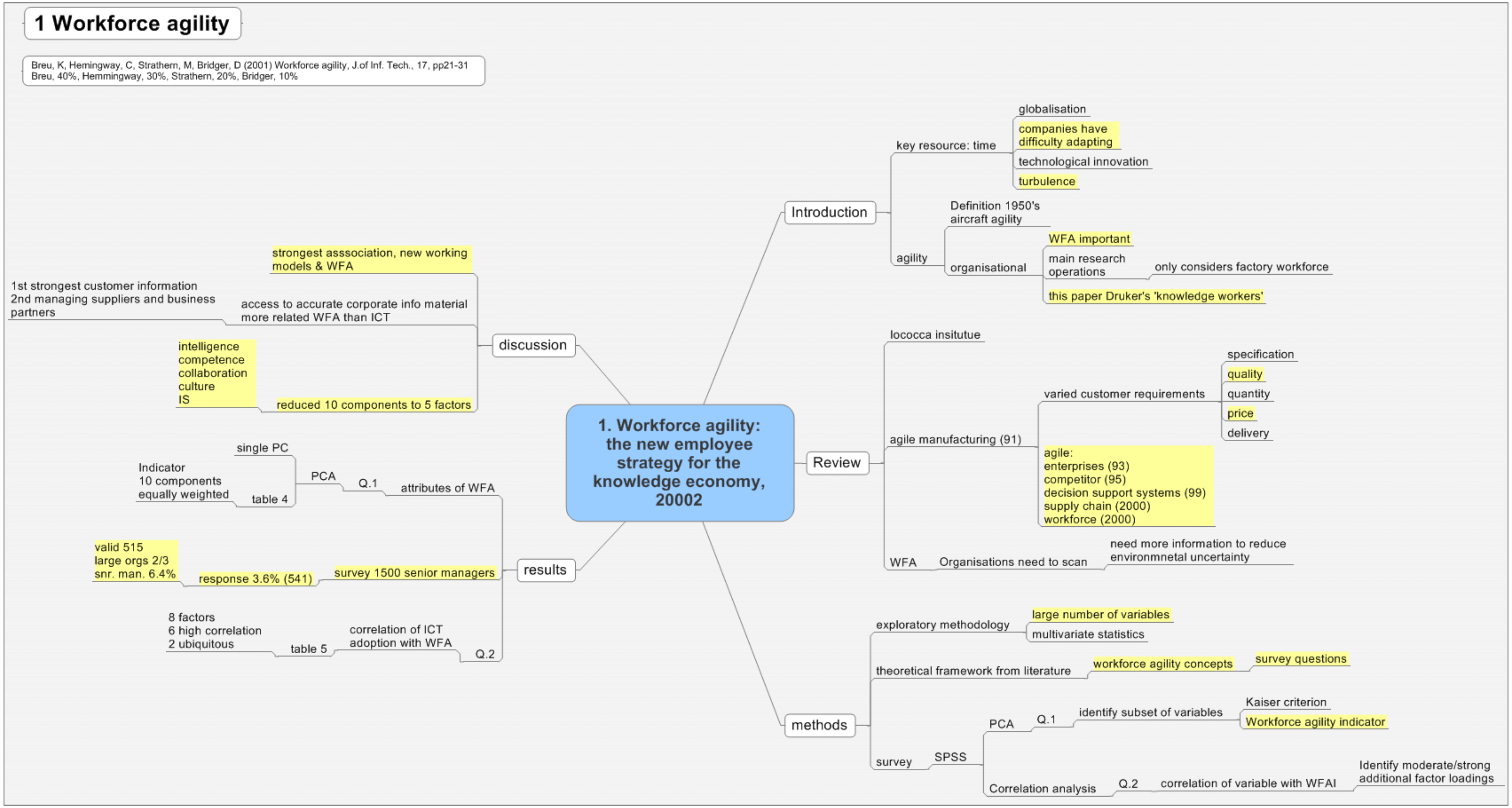
There is some further evidence and arguments to partially support Ormerod's view at the macro scale. The first is the increasing turnover rate in companies in Foster and Kaplan's study (2001). If companies survive longer if they learn, why when they are being exhorted to learn and they employ, in increasing numbers, graduates from business schools who have had this drummed into them, is their failure rate increasing? Also McKinsey (2007) gives evidence from within large companies that managers get it significantly wrong 40 to 70% of the time when it comes to estimates of time, sales, costs and production. They also reported that 40% of managers "hide, restrict or misrepresent information". Under these circumstances there is hidden micro-diversity in the ‘knowledge’ within a company that can lead to disruptive emergent phenomena.

There is also the problem shown in 2005d that in complex systems it is not necessarily possible to learn from within an organisation how changes in behaviour by individuals within it will reflect in global systems behaviour, under these circumstances learning cannot take place. This need for global knowledge 2005d calls the strategy paradox. However it can be possible to work round this by simulating global knowledge and learn by modelling the system and then looking at the global effects of local changes of rules (Datta et al., 2007).

Let us go back to the models in the papers. First a number of models showed that if companies did not learn about their markets, customers, environment and the strategies needed for them then the probability of failure was greatly increased over companies that did learn. But this is only a selector for those who succeed and those who fail, not a predictor of how long a firm will live for. This is a significant point. Learning may be a selector for which companies fail, but not a selector for when, which is what Ormerod's model was looking at. It should also be noted that Ormerod’s model was looking at a quite specific type of knowledge and learning, that is “about the likely impact of their (companies) strategies” (Ormerod, 2003, p.18). This is essentially knowledge and learning about the future, always more difficult than gaining it about the past.

So, both Ormerod's and Senge's views may well be correct from their own particular standpoint, one from the external, environmental view of companies, the other from the internal, managerial view; it is a question of scale. At the macro scale they appeared to fail at random, at the micro scale their survival is at least partially down to their own actions. But in the end organisations are structural attractors and none will survive for ever. The lesson is then that firms should be prepared for the unexpected, and that failure may take them by surprise, when there are sudden environmental changes, but those who are actively engaged in learning and applying it will tend to last longest. As a roman gladiator might have said: those who are about to die salute you (morituri te salutant) - but the gladiator or organisation who has learnt best has a greater chance of surviving longer.

6.0 Summaries of the Submitted Works


1 Workforce agility
Breu, K, Hemingway, C, Strathern, M, Bridger, D (2001) Workforce agility, J.of Inf. Tech., 17, pp21-31
Breu, 40%, Hemmingway, 30%, Strathern, 20%, Bridger, 10%
1. Workforce agility: the new employee strategy for the knowledge economy, 20002
Introduction
key resource: time
globalisation
companies have difficulty adapting
technological innovation
turbulence
agility
Definition 1950's aircraft agility
organisational
WFA important
main research operations
only considers factory workforce
this paper Druker's 'knowledge workers'
Review
lococca insitutue
agile manufacturing (91)
varied customer requirements
specification
quality
quantity
price
delivery
agile:
enterprises (93)
competitor (95)
decision support systems (99)
supply chain (2000)
workforce (2000)
WFA
Organisations need to scan
need more information to reduce environmnetal uncertainty
methods
exploratory methodology
large number of variables
multivariate statistics
theoretical framework from literature
workforce agility concepts
survey questions
survey
SPSS
PCA
Q.1
identify subset of variables
Kaiser criterion
Workforce agility indicator
Correlation analysis
Q.2
correlation of variable with WFAI
Identify moderate/strong additional factor loadings
discussion
strongest asssociation, new working models & WFA
access to accurate corporate info material more related WFA than ICT
1st strongest customer information
2nd managing suppliers and business partners
reduced 10 components to 5 factors
intelligence
competence
collaboration
culture
IS
results
attributes of WFA
Q.1
PCA
single PC
table 4
Indicator
10 components
equally weighted
survey 1500 senior managers
response 3.6% (541)
valid 515
large orgs 2/3
snr. man. 6.4%
Q.2
correlation of ICT adoption with WFA
table 5
8 factors
6 high correlation
2 ubiquitous

6.1 Workforce agility: the new employee strategy for the knowledge economy

Karin Breu, Christopher J. Hemingway, Mark Strathern, David Bridger
Journal of Information Technology, **17** (1) 21-31.

Today organisations operate in an environment with time as a key resource. Globalisation and turbulent environments are compelling organisations to manage uncertainty more actively. One of the key factors that they can use to do this is agility, which was a concept developed in the 1950s to describe manoeuvring in aircraft. In the 1990s this concept was adopted in manufacturing by the Ioccoca Institute, and later into a wider organisational context. Organisations have been argued to need an agile workforce, but most research so far has concentrated on the shopfloor. This paper uses the term workforce not to refer to shopfloor workers but rather to Drucker's 'knowledge workers'.

In these circumstances workforce agility implies that organisations have scanned their environment in order to anticipate future requirements. They need more information to reduce environmental uncertainty. A study of the literature on workforce agility isolated 10 agility attributes, see table 1, page 23. However there is no theory identifying its concepts or indicators. An exploratory methodology was therefore adopted and data on a large number of variables was collected through a survey. Multivariate statistical analysis was then used to isolate a sub set of variables with a common underlying structure. A combination of principal components analysis (PCA) and correlation analysis was used to reduce the large number of independent variables systematically to a coherent set.

A set of survey questions was developed from the workforce agility concepts shown in table 2, which in turn were developed from the 10 agility attributes of table 1. A postal survey was sent to 15,000 senior managers from UK private and public sector organisations in spring 2001. The database used was known to cover a reasonably even distribution of industry sectors and business functions. There were 540 (3.6%) responses received out of which 515 were valid. There was a strong bias towards senior management (67.4%) with the rest having management roles below the department level.

PCA showed a single component satisfying the Kayser rule with an eigenvalue value of 3.725. It was found to consist of 10 variables with a moderate to strong factor loading and to account for over 37% of the variance (see table 4). The 10 variables were equally weighted as they were all within 15% of the mean factor loading and summing those variables provides an indicator for agility levels of organisations. The distribution of scores is shown in Figure 1, with the vast majority falling in the range of 20 - 26, and only less than 10% achieving a high agility score in the range 28 - 30.

Correlation analysis was used for determining whether the three factors of adoption of ICTs (information and communication technologies), availability of IMS providing consistent and accurate information, and the uptake of new working models, had any positive association with workforce agility. The availability of IS within an organisation that provided employees with consistent and accurate information, demonstrated more significant associations with workforce agility than ICT adoption per se (see tables 5, 6 and 7).

Overall, the analysis identified 10 key attributes of workforce agility (see table 4), and these were clustered into five higher-level categories that described the capabilities of: intelligence, competencies, collaboration, culture, and IS (see table 8). The combination of intelligence and competencies is identified as constituting the strongest indicator of workforce agility and this corresponds with the literature.

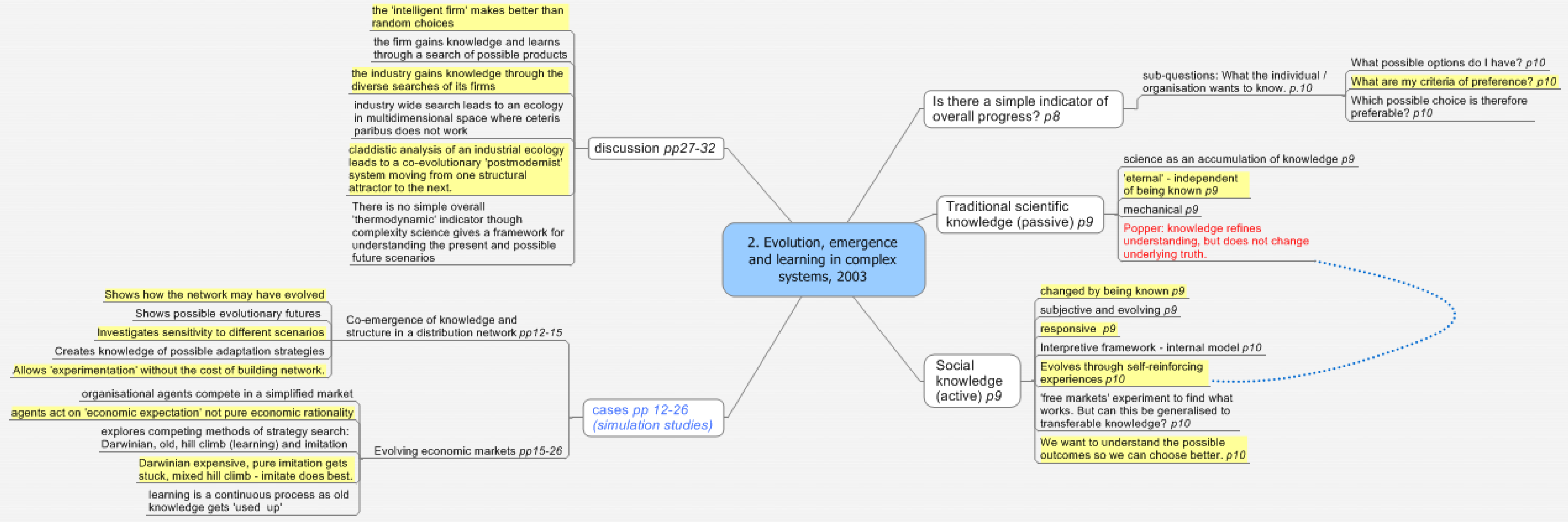
The agility literature argues that speed and flexibility are inconceivable without ICT's, however this research found that it is less the technology that shows a relationship with workforce agility than the novel working models that these technologies enable. Mobile internet and palm top devices appeared to be more strongly associated with workforce agility than the more saturated technologies of mobile phones and e-mail (see table 5). Consistent and accurate corporate information was more strongly associated with workforce agility than ICT adoption (see table 5). Whilst customer information had the strongest association with workforce agility of the range of information types examined (see table 6), however new working models (see table 7), was even more strongly associated. Homeworking, mobile working and hot desking were found to be less strongly associated.

This was exploratory research, so the recommendations can only be tentative developing the capabilities of: work force intelligence, competencies, collaboration, culture and IS, as shown in table 8. The five capabilities are not equally important, intelligence and competencies were the most fundamental elements of workforce agility.

Further research should address the assessment of the external validity of the indicator developed and should look at the costs and benefits of workforce agility, as well as the variations in its relevance across industry sectors.

2. Evolution, emergence and learning in complex systems, 2003

(2003), Allen & Strathern, *Evolution, emergence and learning in complex systems,* Emergence, 5(4), 8-33



6.2 Evolution, Emergence, and Learning in Complex Systems

Peter M. Allen & Mark Strathern

in Emergence, 5 (4) 8-33 (2004)

Is there an overall indicator of progress? If so then we can see some actions and strategies as working with history and others against it. Without a scientific theory of change and transformation social and organisational change could only be driven by trial and error and by peoples accumulating experience and confusion. We need a theoretical framework within which to prove anything about progress, and today we have complexity theory and complex systems science to do this.

The first step to answering the questions is to understand the nature of knowledge. Evolutionary complex systems theory shows that there are two kinds of knowledge: traditional scientific knowledge, where the laws and rules appear to be eternal and unchanging, and therefore there is a process of knowledge accumulation, the second is knowledge concerning people's behaviour and values. This is changed by the process of it being known. This kind of knowledge is part of the evolution of the system itself.

Scientific knowledge is passive, and produces a mechanical view of the universe. Social knowledge on the other hand is changed by being known and is subjective and evolving. Rational behaviour implies that actions on the whole are in agreement with what has been learnt; that through a process of knowledge acquisition and learning an interpretive framework is built that evolves as the situations change.

The questions any organisation or individual wants to address may be summarised as: What possible options do I have? What might be the outcomes of these? What are my criteria of preference? Which possible choices therefore preferable?

Free markets experiment to find out what works. But does this produce transferable knowledge? What we need to understand, so that we can choose better the possible outcomes.

As a first example, we consider a simple logistics problem. The distribution of photocopiers in the UK from a central point of production. The distribution is achieved by setting up one major depot and for some depots at different locations. The question is, what are the best locations for the sub centres. This was studied by building a self organising model, where the decisions of potential customers and where they would buy their photo copier from given the costs of transportation, and the overhead caused by running the distribution centre.

The model evolves from an initial condition where every zone is a sub centre. The costs involved lead to the suppression of small sub centres of distribution, and the growth of a number of main centres. The customer behaviour changes during the simulation from being essentially random to being highly directed to a large centre that is nearest a particular pattern of centres emerges from the many possible. This experiment, shows us the co-emergence of structure and knowledge of the structure. However, when people always go to the best centre it may become routine, and in doing so, they may forget why they are doing this, hence the knowledge will erode.

This model has actually created knowledge by being able to find fairly effective structures and make choices that were better than random. This has been done at a much lower cost than trial and error.

A second model considers an economic market in which there are several competing firms and their potential customers. To produce goods inputs and labour are used and there are fixed overheads and start-up costs. The goods are then sold by sales staff that interact with potential customers to turn them into actual customers. The potential market is related to the quality and price of a product. As a result of building the initial model a credit limit for each company was added. Initially the model had been built so that firms responded to above normal profits expanding and reduce production if they were making losses. However, at start-up firms make negative profits and immediately shutdown. The behaviour of firms could not be represented as present profit maximisation, expected profits had to be included in the equation. This is a simple example of how the model helps us anticipate problems in the real world.

The model was used to explore competing methods of strategy search, in order to discover robust and successful strategies viewed in the real world. There were three pure strategies tested. The first was a "Darwinian" purely random approach where unsuccessful firms are killed off and then relaunched with random parameters, which showed that this leads eventually to a fairly sensible distribution of the firms in possibility space.

The second was a hill-climbing approach, where firms systematically explore whether higher or lower quality and higher or lower markups lead to greater profit, which showed that this was very successful for an individual firm, where the others do not apply. However, if all firms hill climb, their mutual interaction reduces the advantage of learning, but also reduces the number of bankruptcies.

And finally a mimicry approach in which a firm monitors the market and adapts its production to copy which ever firm is most profitable. This leads to a greater concentration in strategy space, and therefore higher competition. What seems like a risk adverse strategy is in fact the opposite. Imitation in a market of imitators is highly risky.

A previous fishing model has shown the importance of micro-diverse strategies rather than pure ones. The next simulation showed what happens when we adopt this strategy and some firms imitate winners, whilst others hill climb. This leads to an overall market structure that has the largest total profits, and a small number of bankruptcies.

In Figure 11, we showed the overall outcome for four different learning strategies, the Darwinian one, the old strategy of if profit is less than half average cut prices by reducing profit, hillclimbing, half the firms are imitators whilst the other half were hill climbers. Each of these was run four times with a different random seed and this showed how for identical initial conditions there were different outcomes emerging depending on luck.

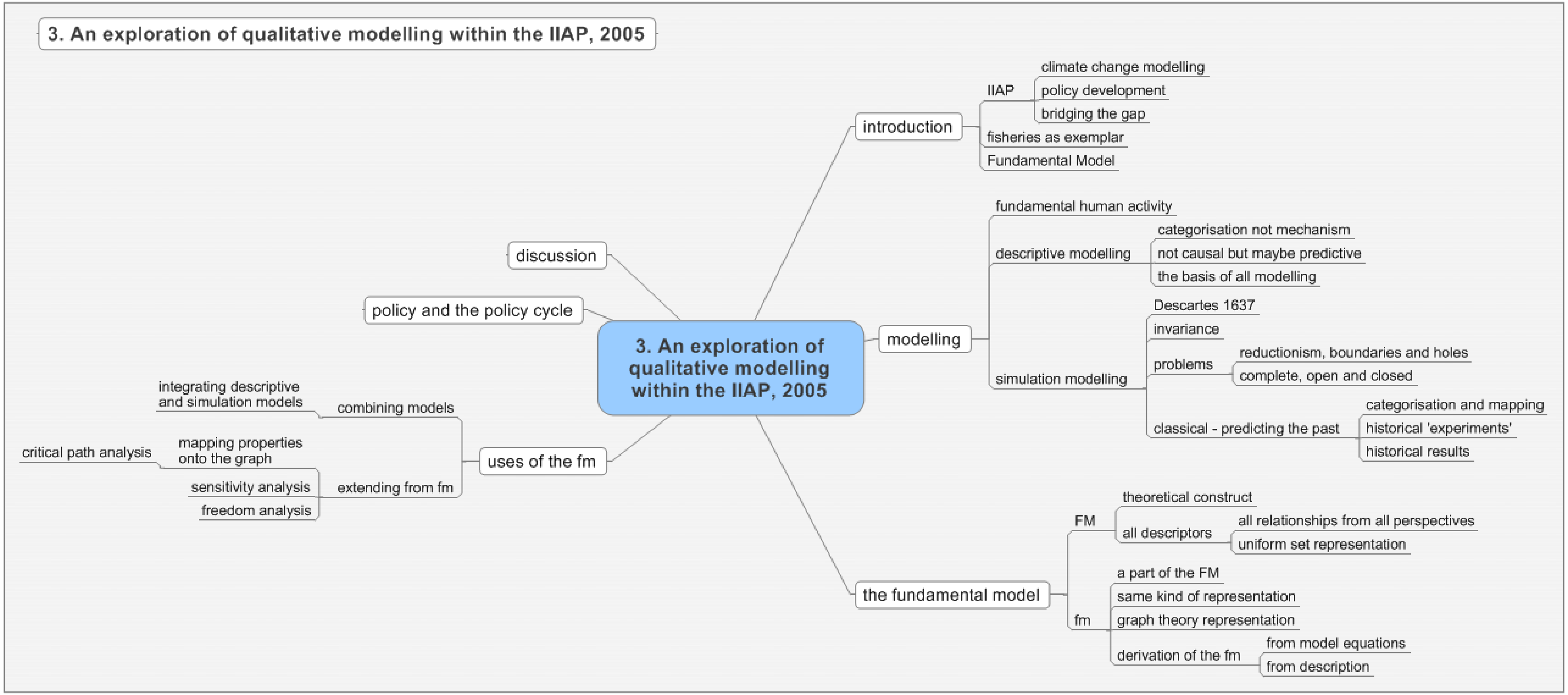
The simple evolutionary models show the importance of learning and sense making. Strategic knowledge needs to evolve as past knowledge invalidates itself, and knowledge uses itself up.

These models allow us to learn about resilient strategies, and not only discover the emergent behavioural rules for firms but also the rules about how to learn. This is a key issue since real innovations concern new dimensions or attributes which confer a temporary monopoly on first movers. This process builds an ecology of firms and products, which will fill the niche is in a multi dimensional attribute space.

We can see from this that evolution and learning give rise to products and strategies that satisfy people's requirements. But this needs a search mechanism. Darwinian search can be very wasteful, and what is needed is a sufficient micro-diversity. This leads to a greater product exploration and better market structure that if firms merely imitate each other, because mechanisms that lead to micro-diversity show emergent knowledge at the level above.

Each agent in an economic network tries to make choices that are better than random using an interpretive framework. Figure 12 shows the mechanisms necessary for a firm to respond intelligently to possible threats or opportunities. This picture operates on multiple timescales. At a microscopic scale, subcomponents will be designed, at the next level. A new design or product will be evaluated, and on a longer timescale strategy itself will be subject to possible renewal. We rely on diverse novel ideas, but we try to anticipate the fate of new products, by devising tests that allow us to launch only those that would seem to be successful.

So, a firm creates knowledge by wide search and assessment of possible products but the industry further creates knowledge through the searches of its diverse firms. Everything rests on structure and micro diversity at one level building search and new structure and micro diversity at the next higher. We hope to make better than random choices, but cannot not know for certain the outcomes.


3. An exploration of qualitative modelling within the IIAP, 2005
3. An exploration of qualitative modelling within the IIAP, 2005
introduction
IIAP
climate change modelling
policy development
bridging the gap
fisheries as exemplar
Fundamental Model
modelling
fundamental human activity
descriptive modelling
categorisation not mechanism
not causal but maybe predictive
the basis of all modelling
simulation modelling
Descartes 1637
invariance
problems
reductionism, boundaries and holes
complete, open and closed
classical - predicting the past
categorisation and mapping
historical 'experiments'
historical results
the fundamental model
FM
theoretical construct
all descriptors
all relationships from all perspectives
uniform set representation
fm
a part of the FM
same kind of representation
graph theory representation
derivation of the fm
from model equations
from description
discussion
policy and the policy cycle
uses of the fm
combining models
integrating descriptive and simulation models
extending from fm
mapping properties onto the graph
critical path analysis
sensitivity analysis
freedom analysis

6.4 An exploration of qualitative modelling within the IIAP

M. Strathern, Prof. P. Allen, Prof. J. Johnson

A study report for the Tyndall Centre, UEA, (2005)

The Tyndall Centre has developed the term Interactive Integrated Assessment Process (IIAP) to cover the whole range of activities in climate change modelling and related policy development. The dialogue between the different processes of modelling and policy development is sometimes incomplete and ill considered. Qualitative modelling approaches can play a significant role in developing the understanding and dialogue needed to bridge between these in some ways, incommensurate activities.

Modelling is a fundamental human activity, which mediates actions in the world to models of it. There are two types of modelling categorised in this paper, descriptive modelling and simulation modelling. Descriptive modelling explains what something is from a particular point of view, and therefore is based on some form of categorisation. It merely describes what is without building, causal links that it can be used predicatively, for instance "red sky at night, shepherd's delight". All models including simulation ones rest on the basis of descriptive modelling.

Simulation modelling is central to climate change studies. The climate as a physical system is theoretically amenable to reductionist approach to understanding it. This methodology has served the physical sciences well. At its heart is the idea of invariance which is the fundamental of all modelling. A model is a reduced description of a partial reality that conveys most of the information that is thought to be important for the particular view being considered. The process of building a model is one of choosing a set of invariants. This is a set of variables (categories), together with a set of invariant dynamics. What is external to the model either at the macro or micro level, which turns it into the real open system, is parameterised or excluded.

This reductionist understanding of modelling brings a number of problems, especially when trans-disciplinary boundaries are crossed, as important parts may be left out. Another important flaw is that of the assumption of completeness, models that work in the lab frequently fails to work in the field. The real world is open, but a model assumes completeness, and therefore closure. Open systems are not at equilibrium can may never arrive there and are by definition, incomplete. It has been shown that open systems behave qualitatively differently to closed ones.

Classically in simulation, a set of mappings is used to produce the model. These mappings and invariants are derived or inferred from observation from a particular view of the system under study. They are based on the past of the system and do not take into consideration its openness. This means that the model, in essence, is based on predicting the past as the future. Policymakers on the other hand are interested in creating the future. In policy then model is not a predictive term deterministic tool (which is how it's built), but a tool for exploring possible futures.

The Fundamental Model (FM) is a purely theoretical construct with a derivative, the fm, which has applications for use in the IIAP. The power of these constructs is in their ability to unify and integrate across pre-existing models of all types. The fm can be used also to derive models that supply useful information without having to build a full simulation model.

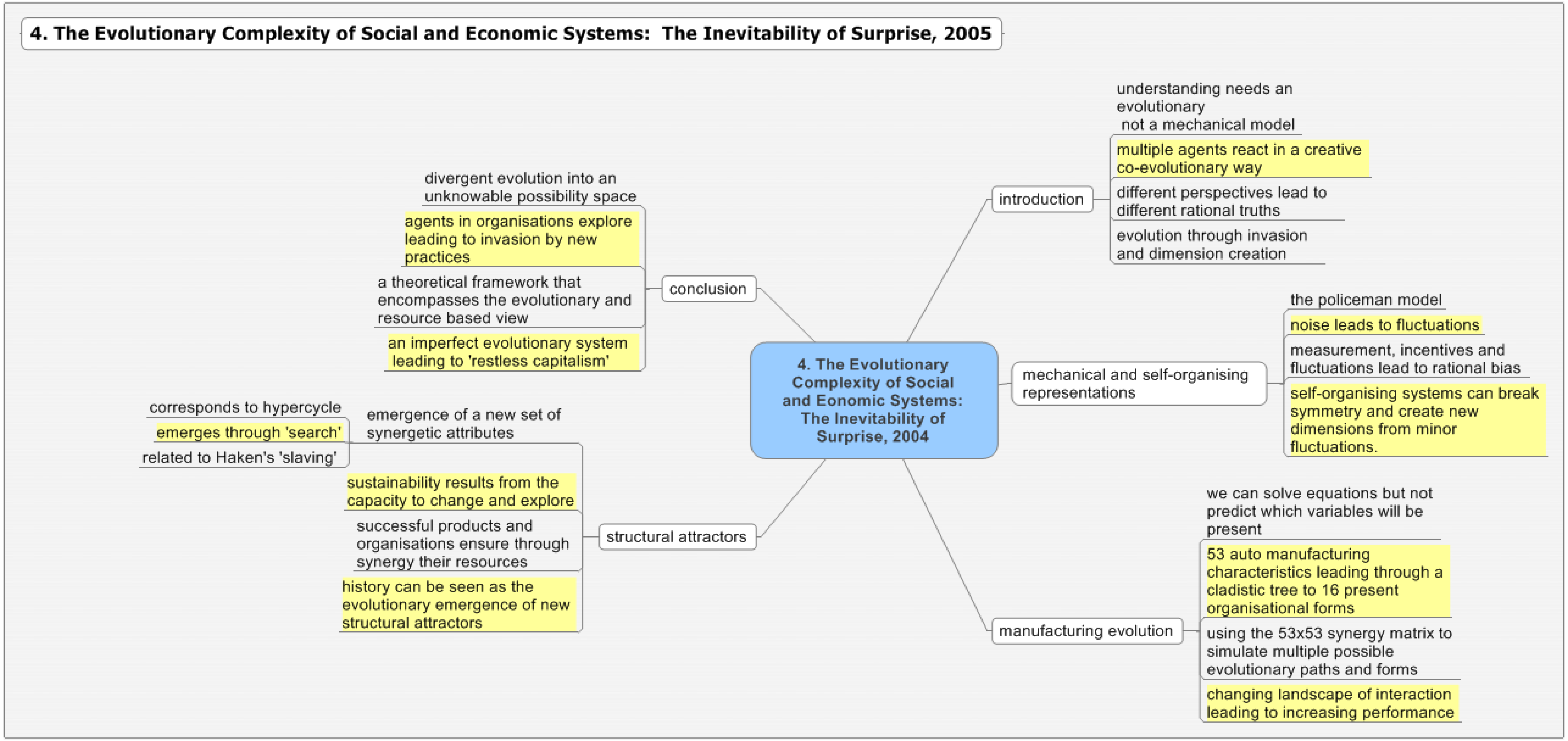
The Fundamental Model (FM) of a system is a uniform set representation of all the possible objects of a system and their relationships with each other from all possible viewpoints. The fm of a system is a part of the Fundamental Model, it is a system as seen from a particular view or set of views, but expressed in the same uniform representation as the FM. It is the lowest level invariant of a particular view of the system.

The there are a number of ways to represent a fundamental model. This paper mainly uses graph theory, in this an object a is related to an object b by a line between two points, one point representing a and the other point representing b. The paper continues, with a description of how to derive the fundamental model of a simple fishing system from a description of the system, and also from a set of equations of the system.

From a fundamental model, we can we can get useful information, and this is shown in page 15 for a number of attributes of a model. Page 16-19, shows how a descriptive modelling can be integrated with a simulation model using the fm and how this can be extended to form a family of models of the system that can give useful information, without necessarily having to build a complete simulation model. Examples are given of use in sensitivity analysis and Freedom Analysis. Freedom analysis looks at a system to try and understand how it will react when changes cause it to move outside its known or modelled dynamic. It looks at this in the terms of what we can say if the fundamental model remains the same, if the fundamental model changes but only in terms of changed relationships, or finally if the fundamental model changes and the number of objects change.

When a system is stressed beyond its known dynamic, in the first instance, the stress can only be felt along those paths that have the dimensions can transmit it, and can only react at those points along those paths that have the freedom to do so. This is true whether the fundamental model changes or stays the same. If it stays the same the point’s freedom takes up the stress in some new non-modelled manner. If it changes it can only change initially along those paths and at those points where the stresses are felt.

In policy development time is a key limiting resource. Policy development is not a unitary and monolithic process but there are stages the process goes through that build the policy cycle. It is important to match the input to the policy process to the stage that it is in the policy cycle.



4. The Evolutionary Complexity of Social and Economic Systems: The Inevitability of Surprise, 2005
4. The Evolutionary Complexity of Social and Eonomic Systems: The Inevitability of Surprise, 2004
introduction
understanding needs an evolutionary not a mechanical model
multiple agents react in a creative co-evolutionary way
different perspectives lead to different rational truths
evolution through invasion and dimension creation
mechanical and self-organising representations
the policeman model
noise leads to fluctuations
measurement, incentives and fluctuations lead to rational bias
self-organising systems can break symmetry and create new dimensions from minor fluctuations.
manufacturing evolution
we can solve equations but not predict which variables will be present
53 auto manufacturing characteristics leading through a cladistic tree to 16 present organisational forms
using the 53x53 synergy matrix to simulate multiple possible evolutionary paths and forms
changing landscape of interaction leading to increasing performance
conclusion
divergent evolution into an unknowable possibility space
agents in organisations explore leading to invasion by new practices
a theoretical framework that encompasses the evolutionary and resource based view
an imperfect evolutionary system leading to 'restless capitalism'
structural attractors
emergence of a new set of synergetic attributes
corresponds to hypercycle
emerges through 'search'
related to Haken's 'slaving'
sustainability results from the capacity to change and explore
successful products and organisations ensure through synergy their resources
history can be seen as the evolutionary emergence of new structural attractors

6.5 The Evolutionary Complexity of Social and Economic Systems: The Inevitability of Uncertainty and Surprise

Allen, P., Strathern, M. & Baldwin, J. (2004)
in Uncertainty and Surprise in Complex Systems: Questions on Working with the Unexpected, Heidelberg: Springer-Verlag (2004)

In order to improve our quality of life in the successful functioning of organisations we must attempt to anticipate to some degree the different kinds of outcome a policy intervention may have. We cannot do this through a simple mechanical model of the system. Complex systems thinking offers a new integrative paradigm in which to view the multiple subjectivities of the world. This new approach encompasses evolutionary processes in general and not just an economic view of the world and sees complexity as a source of creative interaction and innovation and change.

A systems temporary emergent structure is the result of self reinforcing non-linear interactions of successive evolutionary innovations of the previous system. Rational improvement of systems supposes that the system has a purpose and a measure of performance. But this new structural evolution of complex systems that results from successive innovations has emergent properties and effects that lead to new attributes even new purposes and performances.

A simple model shows how non-linear responses can generate new but false information. Policeman, randomly stop and search people when they appear to be acting suspiciously. There will be a small sampling error, in which pure chance can accidentally create small deviations from the normal distributions around the average of the type of person stopped. If policeman are incentivised to achieve the maximum rate of success arresting criminals then this forms a feedback loop, which will drive the initial purely random deviations in one direction or another. Over time, the police seemed biased. Increased targeting produces a result, but the knowledge it creates is false. This form of self-reinforcing learning is a very general property, and probably underlies much of tacit knowledge. This shows that in understanding social systems we can see that self organising can break symmetry and great real behavioural differences between populations that were hitherto identical.

This shows how micro-diversity can lead to emergent objects and systems that structure the character space in which they inhabit. We can always solve a given set equations, but when modelling the future we do not know what new variables will be present that may lead to new structural attractors and therefore we do not know which equations to solve. The changing patterns, practices and routines can be observed in the development of firms and organisations in an industry and lead to a cladistic diagram showing the evolutionary history of the industry.

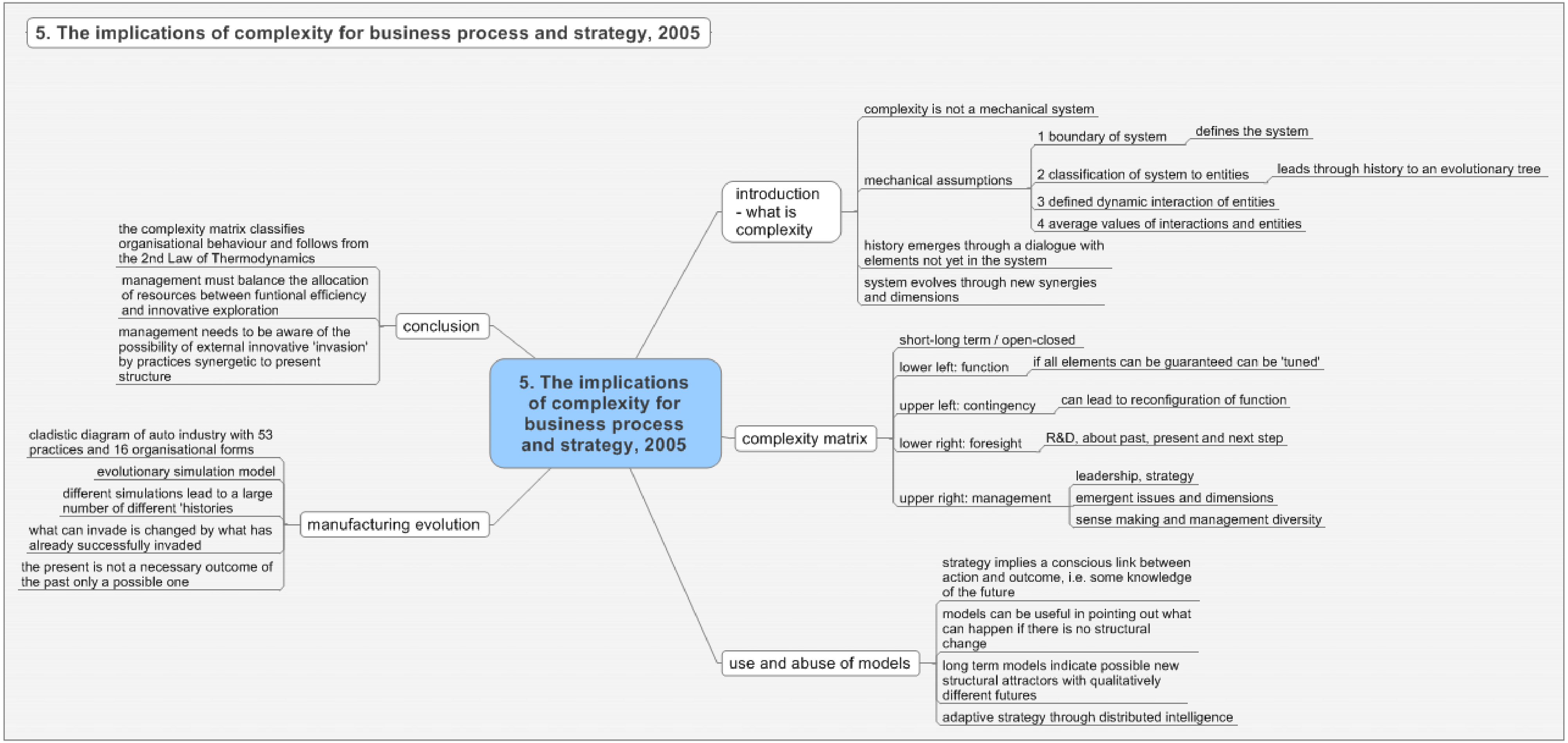
In the automobile industry, McCarthy et al. (1997) have shown that 53 characteristics of manufacturing organisations lead over time through a cladistic tree to produce 16 organisational forms. If we look at the pairwise interaction of the 53 characteristics.

We can look at the internal coherence of these various forms. From a survey of manufacturers (Baldwin 2003) a 53 by 53 matrix of pair interactions was constructed. From this was built an evolutionary model in which as successive practices were introduced a new element of the cladogram was built. This showed the development not only of the present practices but also of other practices that could have been in a different history. One important result of this model shows that over time, as new practices invade the system synergy increases.

This model is very simple and very generic. It shows that for co-evolving agents with underlying micro-diversity we automatically obtain the emergence of structural attractors such as the organisational forms described. A structural attractor is a temporary emergence of a particular dynamical system of limited dimensions, from a much larger space of possible dynamical systems and dimensions. These are complex systems of independent behaviours, whose attributes are on the whole synergetic. What are the implications of structural attractors: search carried out by exploratory diffusion in character space needs to greatly increased performance, process leads to the evolution of a complex community of agents in which positive interactions are greater than negative ones, this the initial homogeneous starting structure of a single characteristic practice is broken by the emergence of new dimensions and attributes sets into new structural attractors.

A successful product or organisation is one which bundles different components and so creates emergent attributes and capabilities that combine to assure it the resources for its production and maintenance. However emergent attributes are not simply additive in effect, if the changes are made in the design of one component it can have multi dimensional consequences for the emergent properties in different attributes spaces.

The divergent evolution into possibility space when agents in organisations explore new practices leads to an invasion of the system. This invasion can only be successful if it draws upon itself sufficient resources to survive. This builds a theoretical framework and encompasses the evolutionary and the resource-based view of organisations. It is not a perfectly optimising system, but an imperfect evolutionary system leading to "restless capitalism".



5. The implications of complexity for business process and strategy, 2005
5. The implications of complexity for business process and strategy, 2005
introduction - what is complexity
complexity is not a mechanical system
mechanical assumptions
1 boundary of system
defines the system
2 classification of system to entities
leads through history to an evolutionary tree
3 defined dynamic interaction of entities
4 average values of interactions and entities
history emerges through a dialogue with elements not yet in the system
system evolves through new synergies and dimensions
complexity matrix
short-long term / open-closed
lower left: function
if all elements can be guaranteed can be 'tuned'
upper left: contingency
can lead to reconfiguration of function
lower right: foresight
R&D, about past, present and next step
upper right: management
leadership, strategy
emergent issues and dimensions
sense making and management diversity
use and abuse of models
strategy implies a conscious link between action and outcome, i.e. some knowledge of the future
models can be useful in pointing out what can happen if there is no structural change
long term models indicate possible new structural attractors with qualitatively different futures
adaptive strategy through distributed intelligence
conclusion
the complexity matrix classifies organisational behaviour and follows from the 2nd Law of Thermodynamics
management must balance the allocation of resources between funtional efficiency and innovative exploration
management needs to be aware of the possibility of external innovative 'invasion' by practices synergetic to present structure
manufacturing evolution
cladistic diagram of auto industry with 53 practices and 16 organisational forms
evolutionary simulation model
different simulations lead to a large number of different 'histories
what can invade is changed by what has already successfully invaded
the present is not a necessary outcome of the past only a possible one

6.6 The implications of complexity for business process and strategy

Peter Allen, Jean Boulton, Mark Strathern and James Baldwin

in Managing Organizational Complexity: Philosophy, Theory and Application, Greenwich, CT: Information Age Publishing Inc. (2005)

Complexity is about the evolution of collective structure in interacting entities. It arose when open systems were considered as opposed to closed ones. A mechanical system is not a complex system, but we can use this to identify the simplifying assumptions that allow us to write down a mechanical representation of reality. The successive assumptions are: 1. that we put boundary around some system of concern to define it, 2. that we know how to classify the different types of entities within it which leads through history to an evolutionary tree, 3. that we can understand what will happen through the dynamical interaction of the entities, 4. that we can consider the interactions in terms of their average values.

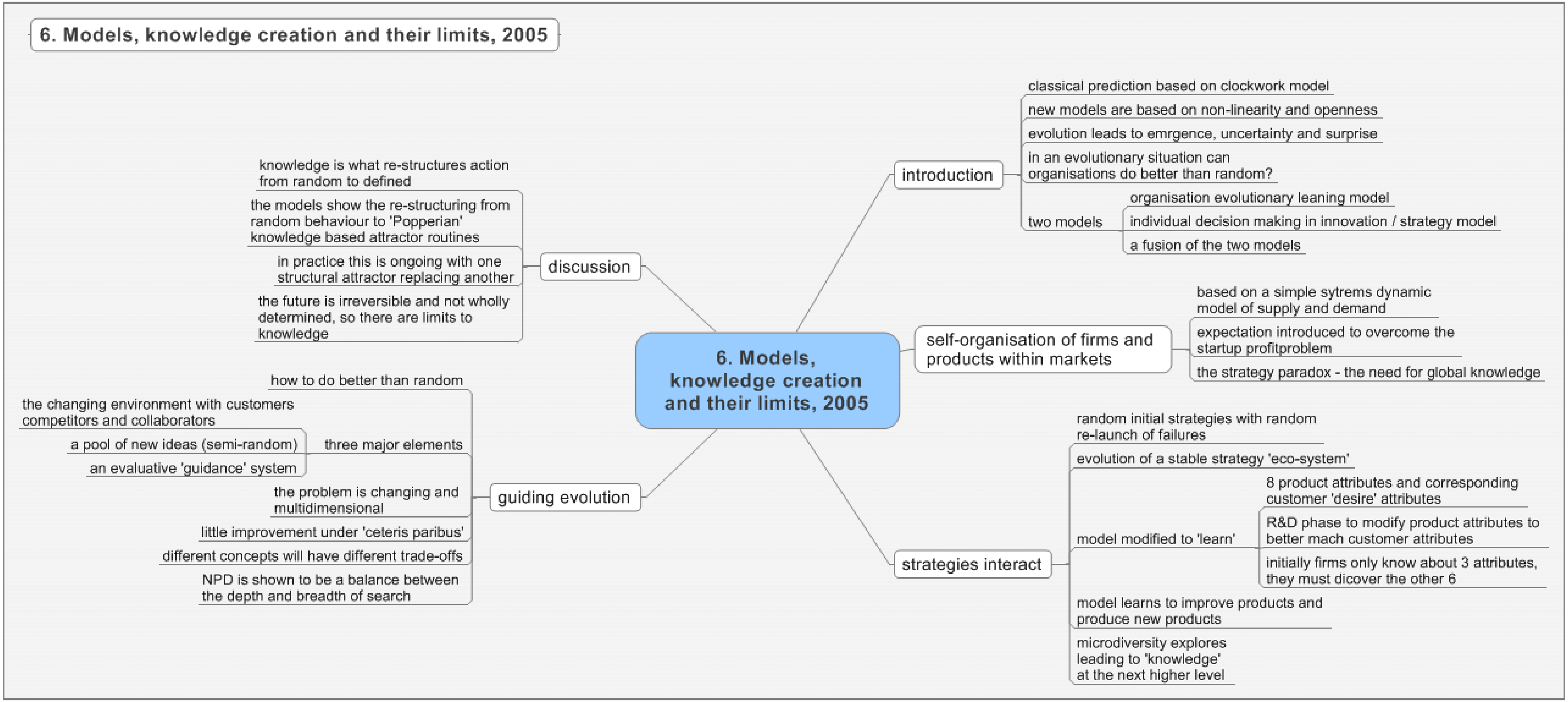
At each stage the successive assumptions create more constrained representations of reality and the history of the system emerges through a dynamic dialogue between the system and elements not already in it. This leads the system to evolve through new synergies to discover new dimensions.

Complexity can be characterised through a complexity matrix that has short term - long term on the x axis and closed – open on the y axis. The lower left quadrant is a function where if all the elements are certain the system can be ‘tuned’ or optimised. The upper left quadrant is short term contingency which can lead to reconfiguration of the function in order to deal with the disruption. The lower right quadrant is where foresight is needed in the form of R&D, about past, present and next step. Finally the upper left quadrant is the realm of management where leadership and strategy are needed to deal with emergent issues and new dimensions, and where sense making and management diversity are important.

The paradox of strategy is that it implies a conscious link between action and outcome, i.e. some knowledge of the future. Here models can be useful in pointing out what can happen if there is no structural change and allow the strategist to ‘know’ and ‘learn’ from the future. Long term models indicate can alert the manager to possible new structural attractors with qualitatively different futures leading to adaptive strategy that is implemented through distributed intelligence.

The cladistic diagram of the auto industry together with the 53 associated practices give rise to 16 organisational forms. An evolutionary simulation model of this using an influence matrix of the53 practices gave different simulations that lead to a large number of different 'histories’. This is because what can invade the system in the future is changed and determined by what has already successfully invaded in the past. So the present is not a necessary outcome of the past only a possible one.

A major insight is that the complexity matrix classifies organisational behaviour and follows directly from the 2nd Law of Thermodynamics. This all means that management must balance the allocation of resources between functional efficiency and innovative exploration to be successful. Management needs also to be aware of the possibility of external innovative 'invasion' by practices synergetic to present structure


6. Models, knowledge creation and their limits, 2005
6. Models, knowledge creation and their limits, 2005
introduction
classical prediction based on clockwork model
new models are based on non-linearity and openness
evolution leads to emrgence, uncertainty and surprise
in an evolutionary situation can organisations do better than random?
two models
organisation evolutionary leaning model
individual decision making in innovation / strategy model
a fusion of the two models
self-organisation of firms and products within markets
based on a simple sytrems dynamic model of supply and demand
expectation introduced to overcome the startup profitproblem
the strategy paradox - the need for global knowledge
strategies interact
random initial strategies with random re-launch of failures
evolution of a stable strategy 'eco-system'
model modified to 'learn'
8 product attributes and corresponding customer 'desire' attributes
R&D phase to modify product attributes to better mach customer attributes
initially firms only know about 3 attributes, they must dicover the other 6
model learns to improve products and produce new products
microdiversity explores leading to 'knowledge' at the next higher level
discussion
knowledge is what re-structures action from random to defined
the models show the re-structuring from random behaviour to 'Popperian' knowledge based attractor routines
in practice this is ongoing with one structural attractor replacing another
the future is irreversible and not wholly determined, so there are limits to knowledge
guiding evolution
how to do better than random
three major elements
the changing environment with customers competitors and collaborators
a pool of new ideas (semi-random)
an evaluative 'guidance' system
the problem is changing and multidimensional
little improvement under 'ceteris paribus'
different concepts will have different trade-offs
NPD is shown to be a balance between the depth and breadth of search

6.7 Models, knowledge creation and their limits

Peter M. Allen, Mark Strathern
in Futures 37 (7-8) (2005)

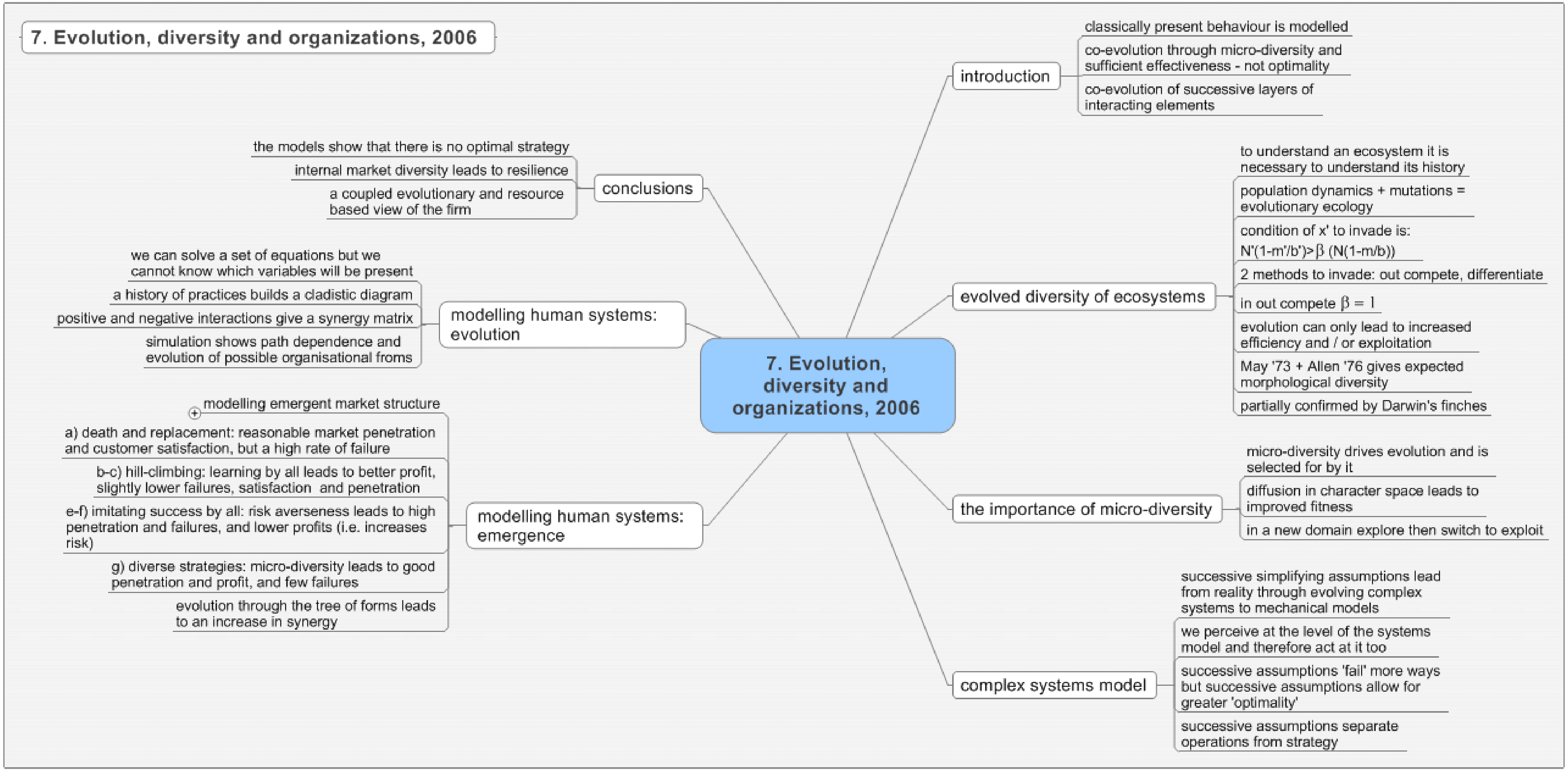
In classical models prediction is based on a mechanical, ‘clockwork’ model of the system. However the new models of complexity science are based on non-linearity and openness which leads to the emergence, uncertainty and surprise of evolution

But in an unknowable evolutionary situation can organisations do better than random? Two models are developed to explore this question, an organisational leaning model and a model with individual decision making in innovation and strategy. A fusion of these two models leads to an evolutionary model that demonstrates the self-organisation of firms and products within markets. This is based on simple systems dynamic model of supply and demand coupled with an expectation of profit, which was introduced to overcome the startup problem of immediate certain loss before any profit is made.

The paradox with strategy is the need for global knowledge. In the model strategies interact. In the initial version random initial strategies interact and there is random re-launch of failures this leads to the evolution of a stable strategy 'eco-system'. A modified model was then built to 'learn'. There were 8 product attributes and corresponding customer 'desire' attributes with an R&D phase to modify product attributes to better mach customer attributes. Initially firms only know about 3 attributes, they must discover the other 6. The model learns to improve products and produce new products using micro-diversity it explores the possibility space leading to 'knowledge' at the next higher level.

Guiding evolution: how to do better than random? The idea here is based on three major elements, the changing environment with customers, competitors and collaborators, a pool of new ideas (semi-random), and an evaluative 'guidance' system. The problem is changing and multidimensional and there can be little improvement under 'ceteris paribus' because different concepts will have different trade-offs. This shows that new product development (NPD) is a balance between the depth and breadth of search.

Knowledge is what re-structures action from random to defined. The models developed in this paper show the re-structuring from random behaviour to 'Popperian' knowledge based attractor routines. In practice this is ongoing with one structural attractor replacing another and the future is irreversible, not wholly determined, so there are limits to knowledge.


7. Evolution, diversity and organizations, 2006
7. Evolution, diversity and organizations, 2006
introduction
classically present behaviour is modelled
co-evolution through micro-diversity and sufficient effectiveness - not optimality
co-evolution of successive layers of interacting elements
evolved diversity of ecosystems
to understand an ecosystem it is necessary to understand its history
population dynamics + mutations = evolutionary ecology
condition of x' to invade is: N'(1-m'/b')>β (N(1-m/b))
2 methods to invade: out compete, differentiate
in out compete β = 1
evolution can only lead to increased efficiency and / or exploitation
May '73 + Allen '76 gives expected morphological diversity
partially confirmed by Darwin's finches
the importance of micro-diversity
micro-diversity drives evolution and is selected for by it
diffusion in character space leads to improved fitness
in a new domain explore then switch to exploit
complex systems model
successive simplifying assumptions lead from reality through evolving complex systems to mechanical models
we perceive at the level of the systems model and therefore act at it too
successive assumptions 'fail' more ways but successive assumptions allow for greater 'optimality'
successive assumptions separate operations from strategy
conclusions
the models show that there is no optimal strategy
internal market diversity leads to resilience
a coupled evolutionary and resource based view of the firm
modelling human systems: evolution
we can solve a set of equations but we cannot know which variables will be present
a history of practices builds a cladistic diagram
positive and negative interactions give a synergy matrix
simulation shows path dependence and evolution of possible organisational froms
modelling human systems: emergence
modelling emergent market structure
a) death and replacement: reasonable market penetration and customer satisfaction, but a high rate of failure
b-c) hill-climbing: learning by all leads to better profit, slightly lower failures, satisfaction and penetration
e-f) imitating success by all: risk averseness leads to high penetration and failures, and lower profits (i.e. increases risk)
g) diverse strategies: micro-diversity leads to good penetration and profit, and few failures
evolution through the tree of forms leads to an increase in synergy

6.8 Evolution, diversity and organization

Peter Allen, Mark Strathern and James Baldwin
in Complexity and Co-Evolution, Edward Elgar (2005)

Throughout this book the nature and mechanisms that drive change in the economic, social and spatial structures of human systems are discussed. This is often supposed to be quite distinct from the evolution of natural systems, since human intention and intelligence is assumed to constitute a qualitative difference. However, we shall show that this is not really the case when the complex and emergent nature of systems robs us of predictive power and knowledge, and makes our actions as exploratory as that generated by genetic variation. When we examine models of natural evolution such as those of Evolutionary Stable Strategies (Maynard-Smith 1979), we see that they contain mechanisms of reproduction and mortality whose repeated action over time leads some population types to flourish and others to decline. In other words they are closed models that are only able to discuss single steps in the whole chain of events. These models of evolution do not ask where new 'behaviours' come from, but simply show that, if several are present, then under competition some will grow at the expense of others. The idea is that, in the natural world that surrounds us, such eliminations have already occurred, and what we see is the 'outcome' of such a process, all the marvellously adapted, mutually interdependent behaviours of living creatures. Behind this is the idea of evolution as an optimizing 'force', which has led to the retention of the organisms we see because of their functional superiority. In other words, in this view, behavioural optimality characterizes the organisms that inhabit a 'mature' system. Indeed, this naïve speculation is then used 'backwards' by 'optimal foraging theory', which says that the behaviour of individuals is 'explained' as being optimal within the circumstances within which it resides. Such ideas echo those of neoclassical economics in which the behaviour of firms or individuals is supposedly 'explained' as that which provides optimal profits or utility respectively.

But we disagree with this view. In general, each species is in interaction with others, and therefore evolutionary improvements may lead to greater synergy or conflict between behaviours, and in turn to lead to a chain of responses without any obvious end. And if there is no end, then the most that can be said of the behaviour of any particular individual or population is that its continued existence proves only that it is sufficiently effective – but not that it is optimal.

Our aim here is to show that the underlying mechanisms that drive evolution are the mechanisms that generate micro-diversity within a system, and how this in turn drives an evolving system structure, characterized by changing structural diversity. This view automatically creates co-evolutionary ecosystems made up of populations whose behaviours are both the mutual responses and challenges to each other.

Diversity is a measure of the number of qualitatively different types of entity present corresponding to individuals with different attributes. It may be that they share some dimensions, but differ on others. This is an important point because it refers to a fundamental issue for evolution – it concerns the qualitative changes that occur in systems and structures over time. This also introduces another important issue – that of multiple levels of description. In evolutionary systems, the internal nature of the interacting individual entities changes over time, as does the configuration of the interactions between these types, leading to a changing overall system performance within its environment. This presents us with a view in which individuals are bundles of their internal components, the local community or organizations they form are bundles of these individual types, and ecosystems and larger structures they form are bundles of these local communities. The essential feature is that of the co-evolution of successive layers of interacting elements both horizontally and between levels. The diversity of the different levels of structure arises through these co-evolutionary processes that are in turn driven by the generation of micro-diversity – diversity at the level below. To illustrate this, let us consider the simplest possible example. Let us consider how a population evolves. It evolves if new behaviour both invades a population and also grows to a significant level in the system.

In classical systems modelling only the present mechanical behaviour is modelled, but in the new complex systems modelling co-evolution through micro-diversity is included and this allows the past and the future to be expressed, and also shows why the present is as it is. However this means a move away from optimality as there is no longer a single measure of effectiveness, nor a complete knowledge of it. This leads to the criteria being sufficient effectiveness - not optimality. In reality systems are the co-evolution of successive layers of interacting elements not mechanical systems.

To understand an ecosystem it is necessary to understand its history; why it is as it is. If we take mechanical population dynamics and add mutations we arrive at the fuller picture of evolutionary ecology. We need to look at how a mutant population x' can invade a population x, the criterion for x' to invade is:

$$N'(1-m'/b')>b\,(N(1-m/b))$$

There two methods for this invasion to take place: the mutant can out compete the original population, or the mutant can be sufficiently differentiated from the original population so that it does not compete. In the out competing case b = 1 in the above equation. Because of this criterion evolution can only lead to increased efficiency or exploitation, or both.

Taking the Competitive Exclusion Principle of May (1973) and combining it with the evolutionary criterion of Allen (1976) gives the expected morphological diversity, and this is partially confirmed by the work done Darwin's finches on the Galapagos Islands.

This emphasises the importance of micro-diversity and shows how micro-diversity both drives evolution and is also selected for by it. Thus diffusion in character space leads to improved fitness, and in a new domain this will dominate whilst exploration pays off and then there will be a gradual switch to exploitation.

In understanding complex systems modelling we learn how successive simplifying assumptions lead from reality through evolving complex systems models to mechanical models. Normally we perceive at the level of the systems model and therefore act at it too. As each successive simplifying assumption is made the system can 'fail' in more ways, but successive assumptions allow for greater 'optimality'. It is these successive assumptions that separate the non-optimisable formulation of strategy from the optimisability of operations.

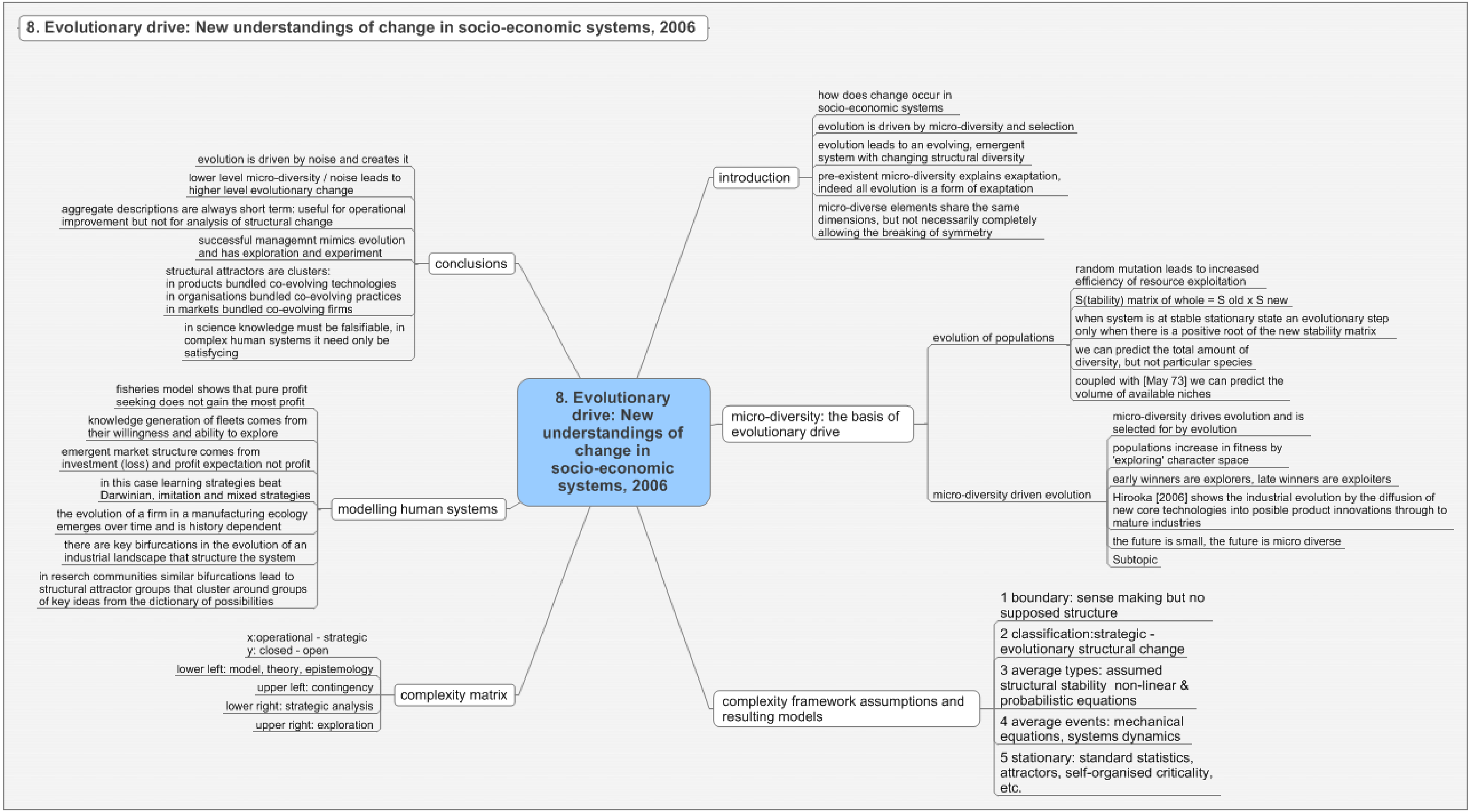
In human systems emergence is a key factor and in the model of emergent market structure the main question addressed is: can firms find strategies that profitably co-exist? Figure 1.15 shows the results from a number of different types of run of the model with different strategies:

a) death and replacement: reasonable market penetration and customer satisfaction, but a high rate of failure.
b-c) hill-climbing: learning by all leads to better profit, slightly lower failures, satisfaction and penetration.
e-f) imitating success by all: risk averseness leads to high penetration and failures, and lower profits (i.e. increases risk).
g) diverse strategies: micro-diversity leads to good penetration and profit, and few failures.

This modelling study also shows evolution through the tree of forms leading to an increase in synergy.

The modelling of human systems is the modelling of evolutionary systems. Because of this although we can solve a set of equations, we cannot know which actual variables will be present. However if we take a history of industrial practices it can be used to build a cladistic diagram of the evolution of the industrial landscape to the present industrial ecosystem. From a survey of manufacturers a synergy matrix of the practice to practice interactions was built showing the positive and negative pairwise interactions. Using this a probabilistic simulation model was built which the shows path dependence and the evolution of possible organisational forms.

One of the lessons from the models in this paper shows that there is no optimal strategy. However another important lesson is that internal market diversity leads to resilience. This gives a coupled evolutionary and resource based view of the firm.


8. Evolutionary drive: New understandings of change in socio-economic systems, 2006
8. Evolutionary drive: New understandings of change in socio-economic systems, 2006
introduction
how does change occur in socio-economic systems
evolution is driven by micro-diversity and selection
evolution leads to an evolving, emergent system with changing structural diversity
pre-existent micro-diversity explains exaptation, indeed all evolution is a form of exaptation
micro-diverse elements share the same dimensions, but not necessarily completely allowing the breaking of symmetry
conclusions
evolution is driven by noise and creates it
lower level micro-diversity / noise leads to higher level evolutionary change
aggregate descriptions are always short term: useful for operational improvement but not for analysis of structural change
successful managemnt mimics evolution and has exploration and experiment
structural attractors are clusters: in products bundled co-evolving technologies in organisations bundled co-evolving practices in markets bundled co-evolving firms
in science knowledge must be falsifiable, in complex human systems it need only be satisfycing
micro-diversity: the basis of evolutionary drive
evolution of populations
random mutation leads to increased efficiency of resource exploitation
S(tability) matrix of whole = S old x S new
when system is at stable stationary state an evolutionary step only when there is a positive root of the new stability matrix
we can predict the total amount of diversity, but not particular species
coupled with [May 73] we can predict the volume of available niches
micro-diversity driven evolution
micro-diversity drives evolution and is selected for by evolution
populations increase in fitness by 'exploring' character space
early winners are explorers, late winners are exploiters
Hirooka [2006] shows the industrial evolution by the diffusion of new core technologies into posible product innovations through to mature industries
the future is small, the future is micro diverse
Subtopic
modelling human systems
fisheries model shows that pure profit seeking does not gain the most profit
knowledge generation of fleets comes from their willingness and ability to explore
emergent market structure comes from investment (loss) and profit expectation not profit
in this case learning strategies beat Darwinian, imitation and mixed strategies
the evolution of a firm in a manufacturing ecology emerges over time and is history dependent
there are key birfurcations in the evolution of an industrial landscape that structure the system
in reserch communities similar bifurcations lead to structural attractor groups that cluster around groups of key ideas from the dictionary of possibilities
complexity matrix
x:operational - strategic y: closed - open
lower left: model, theory, epistemology
upper left: contingency
lower right: strategic analysis
upper right: exploration
complexity framework assumptions and resulting models
1 boundary: sense making but no supposed structure
2 classification:strategic - evolutionary structural change
3 average types: assumed structural stability non-linear & probabilistic equations
4 average events: mechanical equations, systems dynamics
5 stationary: standard statistics, attractors, self-organised criticality, etc.

6.9 Evolutionary drive: New understandings of change in socio-economic systems

P.M.Allen, M.Strathern and J.S.Baldwin,
in E:CO Vol. 8 No. 2 2006 pp. 2-19

The question explored in this paper is how change really occurs in socio-economic systems, based on the ideas of ‘evolutionary drive’ put forward some years ago (Allen & McGlade, 1987). Evolution is driven by micro-diversity and selection and because of this evolution leads to an evolving, emergent system with a constantly changing structural diversity. It is through the presence of pre-existent micro-diversity that we can explain exaptation; indeed all evolution is a form of exaptation. The micro-diverse elements of a system share the same dimensions, but not necessarily completely and this allows for the breaking of symmetry and the building of new dimensions.

So, micro-diversity is the basis of evolutionary drive. If the evolution of populations is considered it can be seen that random mutation leads to increased efficiency of resource exploitation. When there are changes the stability of the whole can be calculated using matrix algebra by: S(tability) matrix of whole = S_old x S_new
It follows from the matrix algebra that when a system is at a stable stationary state an evolutionary step can only be taken when there is a positive root of the new stability matrix (S new).

Using this maths we can now predict the total amount of diversity, but not the particularity of individual species. If however this is coupled with resource volume (May1973) work on we can ‘predict’ the volume of available niches.

Because micro-diversity drives evolution it is also selected for by evolution. And using this micro-diversity populations increase in fitness by 'exploring' character space. Where a new domain opens up the early winners are explorers, but as the ecology of the domain fills this changes so that in the end the late winners are exploiters. Hirooka’s (2006) study shows how an industry evolves by the diffusion of new core micro-diverse technologies into the possibility space of product innovations. And that as the possibility space is filled the industries mature. Because it is micro-diversity that drives this evolution we can in some sense say that: the future is small, the future is micro diverse

The complexity framework describes a hierarchical set of assumptions that form an increasing set of modelling constraints. Each assumption leads to particular style of modelling. The five assumptions and their associated modelling styles are:

1 boundary: sense making but no supposed structure
2 classification: strategic - evolutionary structural change
3 average types: assumed structural stability non-linear & probabilistic equations
4 average events: mechanical equations, systems dynamics
5 stationary: standard statistics, attractors, self-organised criticality, etc.

The complexity matrix on the other hand is a quadrant diagram with the x axis as operational to strategic, and the y axis as closed to open. The lower left quadrant of closed and operational functions describes such things as: model, theory and epistemology. The upper left quadrant of operational and open functions describes the world of contingency. The lower right quadrant of closed and strategic functions is the realm of strategic analysis. Whilst the upper right quadrant, where freedom is greatest, has open and strategic functions that imply exploration.

The complex systems modelling human systems leads to new understandings in socio-economic systems. The fisheries model shows that pure profit seeking does not gain the most profit. The fleets need to produce new knowledge and this knowledge generation of the fleets comes from their willingness and ability to explore their environment despite the fact that exploration can be a costly and unrewarding enterprise.

In a model of competing firms in a strategy space emergent market structure comes from investment (loss) and profit expectation not just profit. In the case of this particular model setup, learning strategies beat Darwinian strategies, imitation and mixed strategies to come out on top.

In a cladistic model of the evolution of firms in a manufacturing industry an ecology emerges over time and is history dependent. There are key bifurcations in the evolution of the industrial landscape that structure the system. We can see similar dynamics in research communities with similar bifurcations that lead to structural attractors that cluster around groups of key ideas from the dictionary of possibilities.

In conclusion we note that evolution is driven by noise and creates it through lower level micro-diversity / noise that leads to higher level evolutionary change. And we find that aggregate descriptions are always short term; useful for operational improvement but not for the analysis of structural change.

So successful management mimics evolution and has appropriate exploration and experiment embedded in it.

Structural attractors are clusters: in products bundled co-evolving technologies, in organisations bundled co-evolving practices, in markets bundled co-evolving firms. In science knowledge must be falsifiable, in complex human systems it need only be satisficing.

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Appendix A: Declaration

Organisational Evolution and Change :
A Complex Systems Approach

I hereby declare that no part of this work has been presented for any other academic distinction or professional qualification.

Mark Strathern

Appendix B: A list of the submitted works and the percent contribution

Publication	**contribution**
2001 Breu, K., Hemingway, C., Bridger, D. & Strathern, M. (2001) "Workforce agility: the new employee strategy for the knowledge economy", *Journal of Information Technology*, 17 (1) 21-31.	20%
2003 Allen, P. & Strathern, M. (2003) "Evolution, emergence and learning in complex systems", *Emergence*, 5 (4) 8-33.	50%
2005a Strathern, M., Allen, P., Johnson, J., (2005) 'An Exploration of Qualitative Modelling within IIAP' study report for the Tyndall Centre, University of East Anglia	90%
2005b Allen, P., Strathern, M. & Baldwin, J. (2005) "The Evolutionary Complexity of Social and Economic Systems: The Inevitability of Uncertainty and Surprise ", In: . *Uncertainty and Surprise in Complex Systems: Questions on Working with the Unexpected*, Heidelberg: Springer-Verlag	40%
2005c Allen, P., Boulton, J., Strathern, M. & Baldwin, J. (2005) "The implications of complexity for business process and strategy", In: . *Managing Organizational Complexity: Philosophy, Theory and Application*, Greenwich, CT: Information Age Publishing Inc.	40%
2005d Allen, P. & Strathern, M. (2005) "Models, knowledge creation and their limits", *Futures*, 37 (7-8).	50%
2006a Allen, P., Strathern, M. & Baldwin, J. (2006) "Evolution, diversity and organizations", In: . *Complexity and Co-Evolution*, Edward Elgar	40%
2006b Allen, P. M., (2006) M. Strathern, J. S. Baldwin, Evolutionary drive: New understandings of change in socio-economic systems, *E:CO* Issue Vol. 8 No. 2 pp. 2-19)	40%

Appendix C: Signed co-authors declarations